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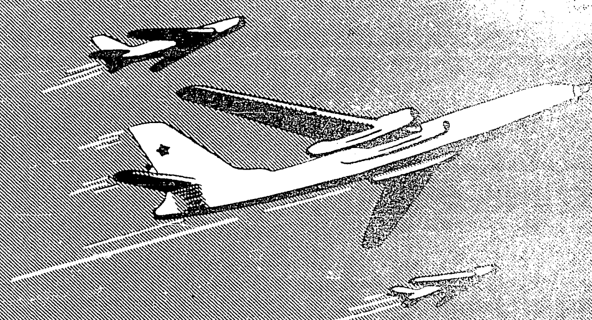
HERALD OF THE AIR FLEET



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HERALD OF THE AIR FLEET
(Vestnik Vozdushnogo Flota)

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TRUE GUARDIAN OF THE SOCIALIST FATHERLAND

Thirty-nine years ago, on 28 January 1918, V. I. Lenin, the creator of the Communist Party and founder of the Soviet state, signed the decree of the Council of People's Commissars for the organization of the Workers and Peasants' Red Army, and on 14 February 1918, a decree was made public, concerning the formation of the Workers and Peasants' Red (naval) Fleet.

In organizing the Armed Forces of the first workers and peasants' state in the world, V. I. Lenin attached great importance to aviation. Upon his instructions, during the very first days after the victory of the October Revolution, the All-Russian Committee for military affairs issued an order for the formation of airplane and airship units as part of the Armed Forces of the Soviet Republic. At the same time a headquarters was organized in Smol'nyy - an office of commissars of airplane and airship units. In his memoirs one of the commissars relates: "I succeeded in having a personal conversation with Lenin on 21 January 1918, when it was already possible to raise the question of the scope and forms of organization of the Red Air Fleet on a wide national scale. I gave a report on the material resources that we had available at the time... Lenin touched on all the basic questions connected with the formation of an air force."

The but recently formed regiments of the Soviet Army were soon after compelled to enter into armed combat with imperialist Germany, which had treacherously attacked Soviet Russia. The soldiers of the Soviet Army resolutely sprang to the defense of the achievements of the Great October Revolution and in fierce battles at Narva and Pskov routed the forces of the German interventionists. Our people have proclaimed 23 February 1918 - the day the hordes of imperialist Germany were routed - as the birthday of the Soviet Army.

Following in the wake of German imperialism, the reactionary circles of the USA, England, and France, hurled the armies of fourteen imperialist countries against the young Soviet republic. The French interventionists landed in Odessa; the British in Archangel; and the Americans in Vladivostok; they were joined by the Japanese.

The Armed Forces of the Soviet Union, led by the glorious Communist Party, defended with honor the achievements of the October socialist revolution by routing and expelling the hordes of interventionists and White Guards from our land. Still more complex and difficult tasks were carried out by the Soviet Armed Forces during the years of the Great Patriotic War which ended in the brilliant victory of our people.

The great victory of the Soviet people in the past war, a victory which eliminated the mortal danger that the Fascist aggressors had posed for the cause of democracy and progress, was an historical landmark in the development of all mankind. Lurking behind Hitlerite Germany which was routed by the Soviet Union were the reactionary forces of international imperialism, above all the capitalist magnates of America and England. Imperialist reaction meant, with the help of German Fascism, to rout or at least weaken the main leading force of growing, all-conquering socialism - the Soviet Union - and thus strengthen its own shaken foundations. The invincible power of the socialist state, the wise policy of the Communist Party, the unbending will of the people and the heroic struggle of the Soviet Armed Forces upset all these calculations of international imperialist reaction.

Having ended the war victoriously, the Soviet state emerged from it stronger than ever before. The strengthening of the Soviet Union, the growth of its international influence, the liquidation of the most dangerous centers of Fascism and aggression, the shift of a number of countries in Europe and Asia to the path of socialist development and the powerful growth of democratic forces in the entire world - all this led to a change in the general correlation of forces between socialism and capitalism in favor of socialism and created the necessary conditions for the establishment of a lasting peace on the basis of international co-operation. The Soviet state, around which rallied the countries of the socialist camp and many millions of supporters of peace, democracy and socialism rises up as an insuperable obstacle in the path of the instigators of a new war.

The war with Fascist Germany which had, with the help of international imperialist reaction, created the most powerful army of all the armies of the capitalist world, was a severe trial for our people and the state they had created. The Soviet people experienced countless privations, fought heroically on the battle front and toiled selflessly on the home front for the sake of the freedom and independence of the socialist Fatherland, and for the sake of the liberation of the peoples of Europe from the Fascist yoke. This great feat of the Soviet Union appeared before mankind in an unfading halo of glory. And no propagandistic tricks by the imperialists can diminish the feeling of gratitude displayed by millions of people the world over to the Soviet people.

The post-war years have brought many new convincing testimonies to the grandeur of the role played by the Soviet Union in determining the fate of many states and peoples of the world. The camp of its friends, supporters of peace and democracy, grows ever stronger, and is turning into an invincible force.

The victory of the Soviet people, of its Army, Air Force and Navy was a new irrefutable affirmation of the viability and durability of the Soviet socialist system, a brilliant manifestation of the power of the socialist state. The war showed that the Soviet system genuinely stems from the people.

The Soviet system gave our people, and our Army, Air Force, and Navy, the great irresistible power which made possible the victory of the Soviet Union over Fascist Germany and then over imperialist Japan as well. The socialist state was the best form of organization of the life of society during the years of peaceful construction. Under the leadership of the Party, our people have in a short time turned their country into the greatest industrial and collective-farm power. The Soviet system proved also to be the best form for the mobilization of all the forces of the people and of all the resources of the country for the achievement of victory in the greatest of all wars, a war the entire brunt of which fell upon the peoples of the Soviet state and upon its Armed Forces.

It is a well-known fact that in modern warfare, victory goes to the state which is stronger than the enemy both in the moral and political sense as well as in the

economic and military. The past war showed that not one of the capitalist countries had, nor indeed could it have, in view of the nature of its social and state structure, the moral and political solidarity displayed by the Soviet people from the beginning and to the very end of the war. Pursuing the wise policy of Lenin, the Communist Party, with the unlimited support of the entire people, assured the victory of socialism in our country, constantly strengthened the dictatorship of the proletariat and relentlessly fought against all attempts to weaken the socialist state.

In organizing the defeat of the enemy, the Communist Party and the Soviet Government leaned upon the material and industrial basis of socialist society, on its moral and political unity, on the brotherly friendship of the peoples of the USSR, and upon the high patriotic consciousness of the Soviet people.

Thanks to socialist industrialization of the country and to the collectivization of agriculture, the economic might of the USSR had grown to enormous proportions. In the pre-war years, we had already occupied first place in Europe and second place in the world in volume of industrial production. The exploiting classes among us had completely been liquidated, and the inequality of peoples in the political, economic, and cultural sense, had been destroyed. The Communist Party had educated the Soviet people in the spirit of love for the socialist Fatherland, in devotion to the concepts of communism and in the spirit of Soviet patriotism and proletarian internationalism.

During the course of the war, the unity of the Party rallied around the Central Committee and was still further strengthened. The Party had mobilized the Soviet people and led them in combat and in labor. Enduring enormous privations and sacrifices, the Soviet people in a well-organized manner and with enthusiasm toiled on the home front, devoting all their efforts to the cause of the defense of the socialist Motherland.

At the beginning of the war, time was needed to set up military production and to satisfy completely the requirements of the front. More than 1300 of the large industrial enterprises alone were evacuated to the eastern regions of the country. New forces were being prepared far to the rear. By the will of the Party, our entire country had been converted into an unconquerable camp, strong in its moral and political unity. The plants were increasing their output of planes, tanks, cannons, mortars, rifles, machine guns, shells, mines and cartridges. The collective farms were increasing the delivery of food supplies to the Front.

The commanding officers, the army political organizations, and the communists carried on extensive party and political work among the troops, strengthening the high combat spirit of the defenders of the Motherland.

After surmounting the difficulties of the initial period of the war and building up strength and experience in conducting combat operations against a powerful enemy, the Soviet Armed Forces routed the Fascists at the approaches to Moscow. With the defeat of the most powerful German-Fascist army group, the Soviet Army seized the strategic initiative. This defeat of the Fascists revealed the weak spots in the Hitlerite war machine. It became clear that in a struggle with a socialist state, the idea of "blitzkrieg" was bankrupt. The Hitlerites' plan for invasion of the British Isles was buried at Moscow. The Soviet people saved the British from a German-Fascist invasion.

After the Battle of Moscow, the Soviet Armed Forces carried out many difficult of America and England. Imperialist reaction meant, with the help of German Fascism, to rout or at least weaken the main leading force of growing, all-conquering socialism - the Soviet Union - and thus strengthen its own shaken foundations. The invincible power of the socialist state, the wise policy of the Communist Party, the unbending will of the people and the heroic struggle of the Soviet Armed Forces upset all these calculations of international imperialist reaction.

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After the Battle of Moscow, the Soviet Armed Forces carried out many difficult but brilliant operations in routing the German-Fascist troops at Stalingrad, Kursk, and Orel, inflicted ten crushing blows in 1944, and conducted the final offensive operations of 1945, which culminated in the capture of Berlin. Within four months after the defeat of Fascist Germany, the other pretender to world domination - imperialist Japan - also laid down its arms.

The victory of our people in the war against German Fascism and Japanese imperialism was a great triumph for Soviet arms. The war proved convincingly that the Soviet system had created the most progressive military organization. The Soviet Army overpowered the enemy, because it had proved to be stronger than its enemy in every respect. Its high fighting spirit, its bravery, and its unprecedented moral force it draws from such sources as the deep-rooted unity of the army with the people, the high and noble aims and tasks, for which it fights, and the wise leadership of their own Communist Party.

The Great Patriotic War subjected to a severe test two essentially different and opposed social and political systems: the Soviet socialist system and the German Fascist state and political system which expressed the most reactionary imperialistic and chauvinistic tendencies of monopolistic capitalism in the contemporary stage of its development. It was the Soviet socialist system that withstood the test.

The Soviet state, national economic, and military organization proved to be the more flexible and more adapted for fighting under the difficult conditions of a modern war with a powerful enemy. The advanced progressive character of the socialist state assured its indisputable advantage in the moral, economic, and military sense.

Throughout the entire glorious course of its development, the Soviet Army has always shown its worth as an army of true patriots of the socialist Fatherland, sacredly fulfilling its patriotic duty to the Fatherland and the people.

The Soviet Armed Forces, as indeed the entire Soviet people, are being educated by our Party in the spirit of respect for the peoples of other countries and in the spirit of love for the workers of the whole world.

During the course of the past war and now, the entire world became convinced of the just nature of the policy of the Soviet state, a policy based on recognition of equal rights of all peoples. This policy governed and still governs the conduct of the Soviet Army. During the war, our troops saw action on the territory of Norway, Finland, Poland, Czechoslovakia, Rumania, Bulgaria, Hungary, Yugoslavia and Korea. Without interfering in the internal affairs of these countries and treating their national sovereignty with respect, the Soviet Army helped these peoples to build their lives in full accord with their own wishes and desires.

Emerging victorious from a grievous war, the Soviet Union ended its international isolation. Today more than a third of mankind constitutes a powerful international camp of socialism, building a happy new life.

The Soviet Armed Forces are observing their glorious thirty-ninth anniversary against the background of a great political and labor upsurge, caused by new remarkable progress in the development of economic and cultural life, and by nationwide competition in honor of the fortieth anniversary of the Great October Socialist Revolution.

The Communist Party and the Soviet Government are bending every effort towards staving off the unleashing of a new war, and towards establishing normal relations among states. The foreign policy of the Soviet Union is a policy of peace and

friendship among all peoples, a policy based on the teachings of the great Lenin with regard to the possibility for peaceful coexistence of two different systems - the socialist and the capitalist.

The imperialists, however, in pursuit of maximum profits, are frenziedly preparing for a new even more destructive war. They have touched off an armaments race, created hundreds of military bases and strong points near the borders of the USSR and of the countries of the people's democracy, and threaten the world with atomic and hydrogen weapons. Pursuing a policy "from a position of strength", the reactionaries have concocted the aggressive North Atlantic bloc, SEATO, and the so-called Bagdad military alliance. Eisenhower's recent speech, in which he glorified the policy of increasing military expenditures, is new proof of the aggressive nature of the policy of the ruling circles of the USA.

The militaristic circles of the USA now no longer conceal the fact that they are interested in the Near and Middle East primarily from the military and strategic point of view, as a base for unleashing new aggression. Recently, for example, in the periodical "United States Naval Institute Proceedings ," Admiral Eller in his article entitled "The Fate of the United States is Being Decided in the Middle East," rejected the hypocritical statements of American propaganda about the "concern" of the USA for the Arab countries and cynically affirmed that the Middle East is oil and the United States needs oil for war: "Without Arab oil we cannot inflict any blows upon the bases of the enemy, we will not be able to safeguard our sea lanes.." and further: "NATO will fall to pieces at once, if the transports of oil and other strategic materials are not safeguarded..We are arming ourselves, but the new types of weapons require a great deal of oil. One jet bomber consumes more than 7 tons of fuel an hour. There will not be enough of domestic American oil alone to carry on a large-scale global war. We have to count more and more on the oil of the Arab countries."

Let's say it openly, the commentaries of Admiral Eller on the infamous "Eisenhower Doctrine" unmask completely the fomenters of war.

The ruling circles of England and France concocted various false allegations in striving to justify their aggression against Egypt. At first they said they had begun the war in order to "break up" the fighting between Israel and Egypt, then it turns out, in order to "defend" their own interests and finally, after having disgraced themselves, they cynically declared that "they were saving" the Arab states from Soviet aggression which the imperialists themselves had trumped up.

During the days when the imperialist camp made an attempt to convert Hungary into a Fascist torture-chamber, and then into a base for unleashing a war in Europe, the bourgeois press unrestrainedly slandered the socialist camp and the Soviet Army and took all steps to support the counter-revolutionary myrmidons.

The crushing of the counter-revolution by the sound democratic forces of Hungary with the help of Soviet troops, extended upon the request of the Hungarian Revolutionary Workers and Peasants' Government, was in the interests of the Hungarian workers and of all peace-loving peoples of Europe, for it put an end to the white terror and averted the danger of creation of a base for aggression in Europe.

In the struggle against the forces of the counter-revolution in Hungary, the Soviet soldiers carried out their sacred duty and defended the world from the imminent threat of war in Europe.

Although pursuing a peace-loving foreign policy, the Communist Party and the

Soviet Government cannot but take into account the fact that reactionary imperialist forces are striving with every means at their disposal to strain and aggravate international tension, and to plunge mankind into a new world war. Under these conditions, the Soviet people, the Communist Party, the Soviet Government, and the Armed Forces are guided by a resolution of the 20th Congress of the CPSU which states that one of the most important tasks is "to take necessary steps for the further strengthening of the defensive power of our socialist state, to maintain our defense at the level of contemporary military technique and science, and to assure the safety of our Motherland."

The thoughts and aspirations of the entire multimillion Soviet people are directed towards securing their peaceful constructive labor and the new powerful upsurge in their economic and cultural life.

On the eve of the new year, there was a regular Plenum of the Central Committee of the CP which had examined the most important problems of economic construction. Its decisions were met with warm approval by the entire Party, and by all Soviet people including the personnel of the Armed Forces.

Soviet soldiers note with particular satisfaction the progress achieved during the past year of 1956, progress in carrying out the decisions of the 20th Congress of the CP in the development of our economy. This progress testifies eloquently again and again to the superiority of the socialist economic system over the capitalist system, testifies to the unlimited possibilities for growth and flourishing of the economic structure in countries of the socialist camp.

The decisions of the Plenum point out that our Party is determined to continue firmly and consistently Lenin's policy of preferential development of heavy industry, which constitutes the indestructible basis of the entire economic structure of USSR.

During the post-war years, the Soviet Army, the Air Force, and the Navy have become more powerful than before the Great Patriotic War. They have at their disposal everything necessary for a reliable defense of the peaceful constructive labor of the Soviet people, and for administering a shattering defeat to every enemy and for bringing him to his senses, if he dares encroach upon the honor, freedom, and independence of our Motherland.

As was noted at the 20th Congress of the CP, the Armed Forces of the USSR now have various atomic and thermonuclear weapons and jet and rocket armament of various types, including long-range rockets, and first-class jet aircraft capable of solving any problems whatsoever that may come up in the event of an attack by an aggressor.

Equipped with new systems of radio navigation and radar, Soviet aircraft now fly at supersonic speeds, long distances, in the stratosphere, under complicated weather conditions and day and night. They are flown by remarkable pilots, ardent Soviet patriots, genuine masters of their craft. In the units and elements of the Soviet Army Air Force, the number of first-class pilots and air navigators is growing continuously, and the overall skill of all the soldier pilots is being perfected. Many of them have earned high government awards.

The number of soldiers who have been awarded the rank of outstanding pilots is growing constantly. The best air gunners, junior aviation specialists, communications men, radar station operators, and soldiers in other branches of the army will meet in Moscow at an All-Army meet of outstanding airmen. This conference

will be a significant event in the life of our Armed Forces personnel. The steady growth of the ranks of "outstanding airmen" is a striking index of progress in the work of the air force commanders of all ranks, evidence of the growth of our soldiers' skill and of the consolidation of order, discipline, and good organization in the units and elements.

Further strengthening of the power of the Soviet Army Air Force constitutes one of the chief concerns of the Communist Party and of the entire Soviet people. The Air Force commanders still have to do a great deal to raise the level of combat readiness, and strengthen discipline and good organization.

Since the 20th Congress of the CP, new tasks have come up to confront the commanders, political organs and party organizations with regard to activization and intensification of ideological and educational work among the pilots. Love for the Communist Party and for our Soviet state and people must be fostered within the entire personnel of the air and maintenance units, and they must be educated in the spirit of lofty Communist principles. The higher the principles of the pilot, the higher his political and professional activity, and the stronger the combat teamwork of the unit and element.

The aviation equipment with which the Air Force is provided is expensive equipment. Its production requires great material expenditures and the persistent labor of thousands of Soviet people. Therefore the duty of the pilot, the navigator, the air gunner, the engineer, the technician, of all aviation specialists is not only to know it well, but also to be concerned with its upkeep and with prolongation of its term of serviceability. Concern for the preventive maintenance of equipment and weapons is manifested in competent care of it, in able operation and finally in striving to enrich one's experience in maintenance by new progressive methods. The desire to make one's contribution in the matter of improving maintenance and utilization of equipment is one of the manifestations of a constructive attitude towards the fulfillment of one's duty in the service.

Examples of fulfillment of military duty are set by Communists and members of the Komsomol. They constitute the greater part of military first-class pilots and navigators. But exemplariness alone is not enough for them. They must constantly assist their comrades in mastering techniques and in perfecting their operational skills. Communist and Komsomol members are called upon daily to help the commanders to instill in the personnel love for the Air Force, good discipline, selfless devotion to the socialist Motherland and readiness to endure any hardships of army life for the sake of guaranteeing the security of the Fatherland.

The realization of personal responsibility for the assigned task is an indispensable condition for high combat readiness and alertness, stable discipline, and inviolate order according to the regulations. During training exercises recently, air commanders V. A. Sulev, I. D. Reydel', and others displayed a high level of training: during the past year they had achieved the highest indices in combat and political training.

Why did they achieve such remarkable results? Why first and foremost because these officers, by setting a personal example in mastering modern aviation equipment, were able to inculcate in their flying and technical personnel the feeling of responsibility for the assigned task.

Everyone of our air commanders, above all must possess a high sense of responsibility for the assigned task. If the commander is exacting towards himself and towards his subordinates, if he is high-principled in his evaluation of the state of affairs, if he does not exaggerate the successes and does not belittle them, and is irreproachably efficient, he will always be able to impart the same attitude towards discharging service responsibilities, to his subordinates as well.

Air commanders A. Ya. Brandys and V. D. Uglyanskiy were able to implant a feeling of great responsibility in their subordinates, owing to the fact that they did not stifle initiative but, on the contrary, encouraged independent action. In each concrete instance, they would let their subordinates feel the entire fullness of personal responsibility placed upon each of them for the task at hand.

Soviet soldiers are proud of their commanders and consider it an honor for themselves to serve the Motherland, and to master military skills under their experienced guidance.

For thirty-nine years, the Soviet Armed Forces have served our great Motherland in faith and truth. The Soviet people are firmly convinced of the fact that they will provide, in the future as well, reliable defense for the peaceful work of our country which is successfully building Communism.

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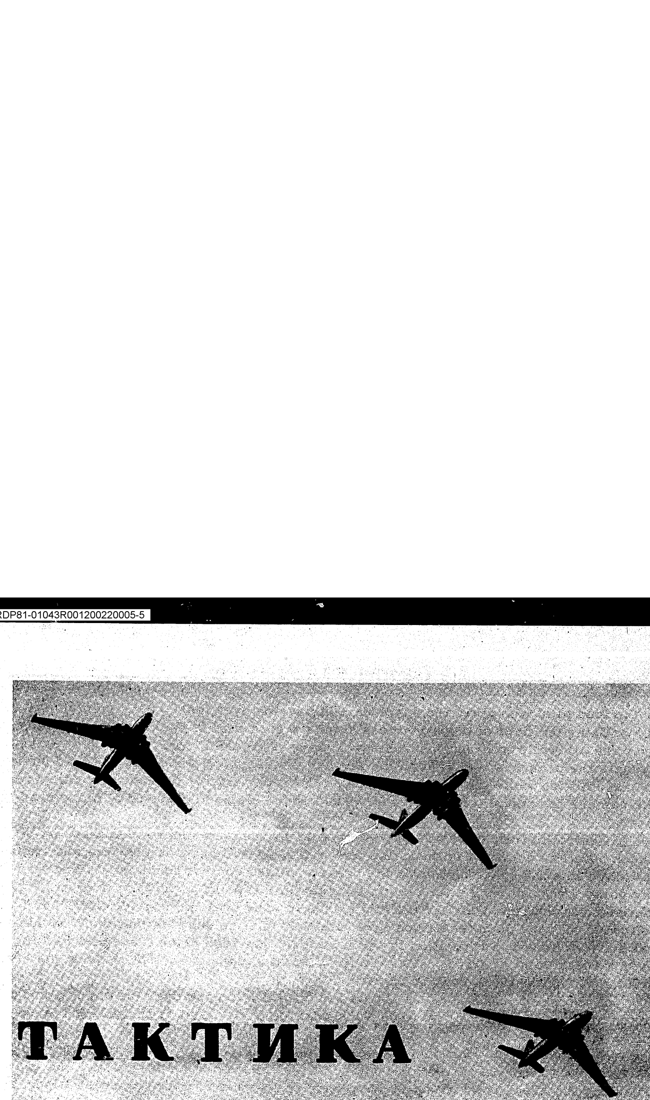

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GROUND CONTROL OF A BOMBER FORMATION ON A NIGHT MISSION

Engineer Major F. S. Pasternak, Major R. Sh. Batalov

On a night mission of single bombers or small formations, the flight or crew commander is compelled in most cases to make independent decisions in flight for lack of possibility of visually observing conditions in the air.

Usually when flying formation, the commander has visual contact with other aircraft which enables him to control their actions. Under these circumstances there is no need of using ground aids for controlling the formation. The ground-control aids are used only to check on the flight course and the bomb run; to help the commander when flight conditions deteriorate and to obtain information about the air situation.

On an independent night or day mission flying formation in the clouds, establishing of control is complicated by the absence of visual communication between the leader of the formation and the aircraft in his formation.

The main problem of control in this case is to maintain consistently the prescribed time intervals and distances in the formation. In practice there are two ways of controlling actual time intervals between planes: by checking the reports of trailing planes as they pass the predetermined check points, or by the commands of the lead pilot who gives the exact time of passing over these check points.

Using the first of these methods entails a good deal of back and forth talking over the air while in flight, because each plane is transmitting. This, however, reveals the presence of planes in the air. In the second method only the lead plane is transmitting while the trailing planes do the receiving. This naturally cuts down the number of transmitted messages. The second method is therefore more practical.

Control of time intervals between planes by the lead commander's report of check points is achieved in the following way. The lead crew determines and transmits by radio the exact time over the predetermined control check points and turning points (when making a turn the time of the initial point of the turn is given). This command is the signal for the trailing planes to pass over the control check point following the lead plane at a fixed time interval. Let us suppose that the time interval between planes in formation is two minutes. The lead plane transmits passing over a check point at 22:00. Thus the first trailing plane passes over the same check point at 22:02 and the second at 22:04.

In the event that one of the planes in trail fails to pass over the check point on time, he tries to adjust his timing on the next leg of flight so as to correct his position in formation.

The advantage of this method lies in the fact that each crew in trail gets its bearings only from the formation leader. Any variation in position of any one crew (reaching the check point ahead or behind time) does not disrupt the entire flight formation.

Nevertheless the task of control is not limited to the transmitting of commands. It is necessary to check the execution of these orders. The commander cannot accomplish this without assistance from the ground, because he is unable to see the aircraft in his formation, which are flying at a considerable distance from him. To keep track of conditions on the bomber's flight path and to maintain check on distances between the planes in formation, it is most effectual to take advantage of ground-based radar stations with a PPI.

The formation in flight is controlled either by flight commander with the aid of data received from ground radar concerning the aircraft flight positions, or by the senior operator at the radar controls. The latter is effectual if the mission is proceeding in a complicated situation, when there are many aircraft aloft.

The possibility of controlling the bomber formation flight by night with the help of data transmitted from a ground radar station, is determined by the proper location of the ground-control point with reference to the bombers' flight path, which should not exceed the station's effective range, thus making it possible to track the planes in their respective positions on the radarscope during the entire flight. This method has the advantage of disclosing immediately a plane's deviation from flight path, or a closer position to each other (reduced distances between them), and provides the means of transmitting such data to the flight commander or of issuing the necessary correction orders directly to the crews.

A responsible officer is assigned to the radar station, where he performs the duties of assistant flight operations officer. He has before him a flight formation diagram, showing the distances between the planes, also the distances between each aircraft and the lead plane, as well as the call signs, designations of all the crews,

a flight chart and flight order.

Before take off of a scheduled flight, the duty officer at the radar station selects a sector on the radarscope in which he can track the formation during its entire flight. The scale of the image should be as large as possible. After selecting the sector and scale of image it would be helpful to trace the flight path of the formation on the glass shield of the radarscope, which will enable the observer to see at a glance the least deviation of the aircraft from its flight path.

The successful control of a bomber formation mission from a ground station depends in a large measure on the clarity, precision and correctness of transmitted commands. Therefore the meaning and character of commands is defined and agreed upon by the formation personnel, in a preflight briefing according to the following rules. As a rule the commands from the ground to the crews aloft are informative in character, i. e. they give the formation commander data on the relative position of planes in formation and any existing deviations from flight path, as well as information about air situation in the general area of flight. The exact degree of deviation from flight path is given as well as position variation in kilometers

Fig. 1. Formation on second leg of flight (the third plane is deviating to the left).

relative to the assigned position in formation. The formation commander decides how and when to correct any course errors if the whole formation has deviated. In case only one plane has deviated the commander of the plane makes his own decision.

An order to execute a definite maneuver is transmitted from the radar station only in emergencies such as a threat of a mid air collision or a change in air situation which demands immediate action.

The commands are brief, concise and directed to the off-position crew.

If it is agreed that the mission should be controlled from the ground by the senior officer, the crews will receive from him orders of execution.

Fig. I gives the photographic sequence of a formation flight in trail at fixed time intervals. The planned flight path is shown in the third frame of this photograph. In the first frame there are three blips showing the planes in formation (they are marked 1, 2, 3). Ahead of the formation is the target designating plane (letter "O").

Even in the first frame it is apparent that the third plane in formation after the first turn has started deviating to the left of the flight path. As the following two frames indicate the degree of deviation gradually increased. There was a time lapse of four minutes between the first and third frame. The third frame was made at the exact moment when the crew of the third plane was informed that it had deviated twelve kilometers from course. Although the message was aimed at the crew which had deviated, it was also received by the formation commander. Consequently he too was informed of the relative position of the planes on the flight path.

Fig. 2. The crew of the third plane corrects the deviation after receiving command from the ground-control station.

As Fig. 2 shows the crew of the third plane understood the command correctly and made the necessary course correction. As a result all the crews approached the second turning point at prescribed distances.

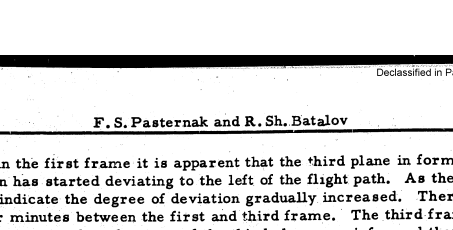

Fig. 3. Formation executing a turn.

Fig. 3 shows the formation making the turn at the second turning point. In the last two frames the lag of the third plane is noticeable. The last frame shows the flight formation heading for the target.

Thus, in this example a command was transmitted only once and it helped the crew of the third plane to correct its course error and to assume its planned position in formation by the time the second turning point was reached.

The commander's successful control of a combat formation mission with the aid of a ground radar station depends on the skill of the radar duty officer in determining from the blips on the radarscope, the relative position of the planes and such flight-line deviations as might occur in the course of a flight.

The greatest problem in monitoring a formation flight is to interpret correctly the correspondence of the blips which appear on the radarscope, particularly when there are many planes aloft. Besides, there are times when blips completely disappear from the screen of the radarscope; this occurs frequently when the planes are making a turn.

In order to determine correctly which plane in formation has deviated from the flight path, the duty officer monitors the flight continuously on the radarscope and transmits commands only when he is convinced that he is sending them to the right aircraft. It is possible to determine which one of the aircraft has deviated from the planned flight path only by quickly comparing the spacings between the blips of all the planes.

The examples analyzed above prove that careful organization of ground control of a night time bomber mission flying under adverse weather conditions can assist the bombers considerably in solving a number of problems connected with the operation.

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TRAINING AND EDUCATION

THE AIR COMMANDER AND FLIGHT SAFETY

Major General of Aviation K. A. Katichev

In organizing flights the air commander must foresee the smallest details. Though this is well known, nevertheless some officers up to this day do not reflect enough on possible exigencies in the course of flight. They live in groundless confidence that the flights will always proceed only as planned.

Of course one must always strive to carry out flights as planned, but at the same time one should foresee the possibility of various emergencies arising and be prepared to meet them fully equipped. Air commanders frequently have to change the order of flights in the course of a flying day because of the weather, disrepair of equipment, failure or interruptions in radio communications - and for many other reasons. It follows that prudence and foresight are important conditions for flight safety.

Foresightedness and constant readiness to make a decision in accordance with changes in situation depend entirely on the thoroughness of the flight's preparation. When all the members of the team know their place and duties the work goes on in a rhythmical and organized way. For a successful solution of these problems, air commanders have to consider all the specific characteristics of flying conditions in their units, insure examplary maintenance of the airfields with all their equipment, require efficient performance of command posts and supporting services, and organize work in such a way that the personnel know their duties and regard them with a deep feeling of responsibility.

The commander generally knows well all the specific characteristics of his airfield, the flight area and the conditions of flight, and organizes these flights according to instructions given for the particular airfield. He sees to it that the flight procedures for the airfield zone and beyond it are stated precisely and are adhered to.

Setting up one or another type of procedure is a long process of persistent work by the command. It is not enough to issue an order and communicate it to the personnel, one has to train men in executing orders in the required manner. This develops in the personnel, habits of meticulous compliance with orders.

Consistency and uniformity of the commander's requirement are very important. Lack of consistency in the organization of flights prevents men from acquiring habits of routine procedure in their work, and creates conditions for their violation. Strict procedure is especially needed in flying as it develops discipline in the personnel, helps them to better master their complicated speciality, and prevents all kinds of unforeseen incidents. If on the other hand the flight procedure is not definite enough or does not correspond to the set requirements, then naturally complications and violations of procedure will follow. Air commanders and all fliers know that the majority of flight accidents happen because of poorly organized flights.

Organizing flights includes a great number of problems: planning, readying of flight personnel and equipment, operational control and so on. All this the air commander has to bear in mind constantly, and he should always keep to the same firm policy, thus ensuring a well organized flight procedure.

In flying the least carelessness often leads to accidents. The commander, therefore, has to observe and notice everything which may ensure successful flight operations. This is not difficult when the flights are well organized. But when the organization is inefficient, so many shortcomings arise that the commander runs the risk of overlooking some of them.

Planning is a very important aspect in organizing flights. Flight safety depends on the soundness of planning. In planning the flights one should not follow any stereotype procedure, nor act hurriedly and thoughtlessly.

Whenever a pilot is given an unduly difficult assignment, whenever gaps in his logged flying time are overlooked, whenever the vagaries of weather or the condition of the airfield and the equipment are not taken into account - the flight performance suffers. In planning flights one has to consider as fully as possible the conditions of every flying day depending on the weather, the condition of the matériel and airfield, level of proficiency of the flight personnel, their physical and morale state, breaks in flying, and so on.

In the unit X, one of the fliers was considered as having finished his solo flight training in adverse weather conditions, although he had not made a single square pattern flight either on a military trainer or on a combat plane. Besides, his flying hours in the clouds amounted to one hour and twenty minutes in all. In addition the flier has had a break of more than two months in his training flights. He was taken on one check flight in a closed-cabin Yak-11 and on another one of eight minutes flying in the clouds in a UTI-MiG-15.

After such "training" the flier was allowed to take a solo flight under minimum weather conditions. As a result of this evident insufficiency of training, in bad weather flying, the pilot twice made an unsuccessful straight-in landing approach. And when he was ordered to make a square pattern landing approach, he made a gross error and fumbled the attempt. Such are the results of violation of systematic training. Such violations cannot but produce poor results especially while flying under adverse meteorological conditions. Air commanders should always bear this in mind.

Sometimes the following incidents occur. If, for instance, for some reason the landing is delayed or becomes necessary to make an additional check on the equipment or have an unplanned short critique with the flight crew, then the whole planned schedule is disrupted. The time of the next flight is then changed. As a result not only the planned schedule but also the chart of aeronautical radio service is disrupted and discrepancy in time follows. And this results from poor planning.

It sometimes also happens that during flights in several shifts the time for the intervals between flights is not considered. So some of the planes are taxying to the start, others away from it, some are taking off, while others, after a delay aloft, are landing. Conditions arise which impair flight safety. The regular order of flights and the whole rhythm of work are disrupted by frequent changes in the flying schedule of the shifts.

It is not always expedient to begin a flying day with intensive flights. For instance, it is much better to increase the intensity of flights gradually after a long break in training flights, in passing from summer to winter flying and vice versa, and also while changing to a new type of aircraft. During the first flights one checks the readiness of the crew and of the aeronautical radio service for a more intensive work. Towards the middle of the day the tempo and intensity of flights will be gradually increased, and decreased towards the end of the day. Such measured training in mastering new aspects of flying will greatly increase safety.

Uninterrupted ground control of flights is of great importance. Defects in ground control may result in serious consequences. For this reason the commander has to see to it daily that every airfield facility is ready to function: that the radio and telephone communication is in working order; that there is always a crash crew available at the start ready to remove from the runway any disabled aircraft; that the surveillance radar is in position, and so forth.

Under these conditions the commander and the operations officer can control the crews aloft easily and with assurance, and if complications in the airfield or in the air occur they have at their disposal all the necessary means to find a way out of any difficult situation in a calm manner.

What are then the basic requirements in organizing flights?

Firstly, the set up has to be in conformity with the directions, instructions and orders given - this is necessary both for flight safety and for uniformity of organization on all airfields.

Secondly, the organizing of flights should be simple and follow the habitual pattern known to the flying crews as well as to all the maintenance and supporting personnel. It is clear, of course, that this does not apply to the flight assignments which may be complicated.

Finally, the planning should be thought out carefully and everything prepared before the flying day.

The first and the strictest guardian of the planned order on the airfield and in the air is the operations officer. Flight safety depends, to a considerable degree, on his experience, his professional attitude and his foresightedness.

Control of flight operations is one of the most complex functions of the air commander because of their dynamics, the sudden complications in air situations and the serious consequences of flight errors. Therefore one has to pay special attention to the selection and training of operations officers.

The duties of an operations officer are set forth in directives and instructions. We shall examine only certain more important sides of (flight) control and follow their effect on flight safety.

If I, as author of this article, would have been asked what are the characteristics of a good operations officer, I would have answered without hesitation: great flying experience and constant alertness. Being alert, the operations officer spots more quickly all flight defects, understands complex situations better, and reacts quicker to errors and omissions of the fliers. Alertness makes you think once again about the weather, alternate airfields, radio communication with the craft - in short about everything which insures flight safety.

The operations officer needs also the quality of foresightedness. I have already spoken about it above, but would like to add that it is impossible to fly or control flights without having reserves. A reserve radio station and an emergency aircraft should always be on duty on the flight line; night take-offs should be planned in case of delay in getting flights off, and during unstable weather a "blindlanding" system should be "ordered." All these measures will help to find a speedy solution in difficult situations.

We shall not dwell here upon the fact that an operations officer has to know his flight personnel, their assignments, check closely the observance of rules and regulations during flights and on the flight line - all this is self-evident. It is more important to point out the new factors which came up in the work of the operations officers these last years.

Since the time when our airfields have become enriched with various equipment for flying in adverse weather conditions, the number of personnel connected with ground control of flights has increased, and the operations officer has many assistants. The commander's work depends on the quality of the work of these helpers. Their errors and omissions are reflected in the course of the flying day. It follows that all those who support the control of flights should know and carry out their duties irreproachably, and in order to achieve this one has to be well prepared in advance for supporting flights.

The operations officer should know well his airfield and the specific characteristics of the given flying area - only then will he be able to understand the action of the fliers and correct their errors in time.

The operations officer's flying experience will always prompt him in deciding how to correct this or that pilot error, what to do when the situation in the air becomes complex, when to allow the take-off, and when to delay or cancel the flights altogether. Without such experience serious trouble is unavoidable.

In one of the units, for instance, adequate measures to ensure flight control by available radio technical means were not taken. The assistant operations officer in charge of the system was absent, and as a result there was no due control over airplanes after the fourth turn in the glide path. The pilot who was in the air was not warned when he dropped below the safe altitude. He saved his plane and himself by sheer luck.

There are many unwritten rules in controlling flights, the majority of which stem from local conditions and specific characteristics and circumstances of each flight. Depending on the nature and conditions of flights, the type of aircraft flown, the weather, the airfield, and so on, ground control of flights may be more or less complex, although in every case it is the most responsible moment in the organization of flights.

With the beginning of practice of intensive flights in adverse weather conditions, the duties of the operations officer increased and his responsibility for the flight safety grew.

Formerly, when pilots used to fly only under visual flight conditions, they could see each other's planes in the air, and changing directions, avoided collisions. There was no need for special airway traffic control. Today pilots, flying under adverse weather conditions, cannot see other aircraft in the air. Besides, other airways may lie on their flight paths in the clouds, where day and night transport planes fly in both directions at various altitudes. The flight paths may also pass through the control zones of other airfields. And finally other craft from other airfields may be following the same flight path. In connection with this there arose the necessity to establish a rigid control of flights, a competent air traffic control.

In this respect aircraft dispatcher service is of great help to the operations officer. It keeps track of the situation in the air and controls the air traffic. But in addition to this the operations officer himself should take care that in adverse weather conditions no flight paths cross air lanes and flight zones of other airfields.

During flights in adverse meteorological conditions the operations officer keeps close contact with the neighboring airfields both for mutual flight safety's sake and in order to create an alternate landing field reserve.

If the airfield lies in the zone of an air lane or near it, then the operations officer has to ensure flight safety for the transit planes.

Let us now examine a few of the most important errors which are sometimes committed in controlling flights.

Operations officers do not always know well enough the air situation, especially over the airfield where the greatest concentration of airplanes occurs. Not having before them a constant picture of the plane traffic, they control the flights "blind" and in so doing commit grave errors.

It also sometimes happens that the operations officer does not know the position of the plane or the group, the conditions of their flight, or what they may meet on their way. This is also bad, and leads to flight accidents.

Next, perhaps the greatest error lies in the fact that sometimes operations officers allow, for no good reason, undue concentration of aircraft on some circle, in the holding pattern zone or in some one area. Some of them do not attach real importance to the fact that too many planes are on the circle, that in the holding area all the echelons turn out to be occupied, that when groups of planes are sent aloft with small time intervals, the air over the area of the landing airfield becomes conjested with planes. Such crowding is dangerous and therefore should be

avoided.

It would be of some interest to discuss the problem of operations officers.

Permanent operations officers are sometimes appointed already during practice flights, and it must be admitted, that flight control in these units becomes better organized.

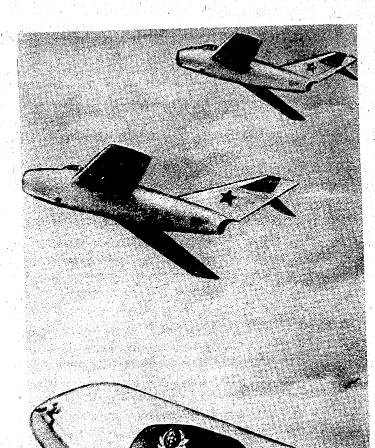
What arguments can be advanced in favor of permanent operations officers?

Ground control of flights, which depends more and more on radio-technical means, has undergone changes and requires the operations officers' constant presence, as they say, at the battle post. The air commander, who generally controls the flights, has many other duties: he has to fly with his pilots, check them in the air or track for errors from the ground; do past flight critiques with them, oversee the work of the technical personnel and flight safety specialists.

It is only natural that under these conditions the commander, serving as operations officer, is distracted from control of flights, while the control has to be an uninterrupted process.

One may argue that a commander has deputies, who could be charged with controlling flights. This is true, but the deputies also have their functional duties, and during flights there is enough work for everyone.

Furthermore, a permanent operations officer will always know better the condition of the airfield, the meteorological conditions and other problems concerning flight safety, in so far as they enter the



Ace interceptor pilot, one of the best flight commanders, military pilot first class, Captain A. Ye. Skobtsov range of his duties. He will work daily on improving the airfield and the radio, lighting and technical means for flight safety, on organizing weather reconnaissance and so forth.

One can object that the operations officer will not always know the level of training of the flying crew and their individual peculiarities. He will know his flying personnel within the necessary limits. In those cases when new fliers are being trained, or some requalification is going on, commanders who know their crews well are always present on the flight line.

Today more and more personnel and equipment are being utilized in controlling flights and in flight safety measures, therefore ground control of flights should be carried out without interruption or distractions. On the other hand, we should train experienced operations officers, keeping in mind that today they represent a fully formed and independent profession in aviation.

And in conclusion a few words on preventive measures against flight accidents.

Air commanders of various categories each have their duties relating to flight safety. But it sometimes happens that commanders, in watching over or duplicating the work of their subordinates, forget their own duties. Of course, every superior commander has to control his subordinate commanders, but at the same time he must not neglect his own work in eliminating causes of flight accidents.

Next one must avoid as much as possible or reduce to the minimum the diversity of flight assignments for any given flying day in a flying shift.

It sometimes happens that several fliers are flying simultaneously, each carrying out a different assignment. It is clear that it is more difficult for the commander to monitor and control such flights. Commanders who concentrate their whole attention on some new or complex kind of flying, and put aside for a time other kinds of flight training, act well in doing so. Such 'one-goal-concentration' helps to master new or complex flight routine faster, better and without incidents.

In striving to achieve accident-free flight training the air commander should always be solicitous, energetic and exacting.

SPECIAL FEATURES OF A LANDING APPROACH WITH THE AID OF A GYRO-INDUCTION COMPASS

Engineer Major A. M. Mikhaylov, Military Flier

Every flier usually encounters some difficulties when executing a landing under adverse weather conditions. These difficulties are caused primarily by the necessity of effectually dividing one's attention between the instruments and holding the aircraft on flight-path and planned approach glide during an instrument landing. The least deviation from flight-path or error in altitude and heading in gliding down may complicate the landing or result in more dire consequences. Under these circumstances it is quite natural that the airmen wish to have equipment and instruments which would facilitate as much as possible their task of piloting the aircraft particularly on the last leg of the landing approach.

At the present time measures are being taken to narrow down the number of instruments whose readings a pilot must watch in flight. This problem is being solved by introducing automation and by combining several instruments into one device. Thus, for example, a gyro-induction compass (GIK) has been developed and is being used in fighter planes. It is a joint indicator combining the readings of the (long range) magnetic gyrocompass DGMK-3 and those of the radio compass ARK-5. As the plane makes a turn, the magnetic course scale turns with it causing the corresponding graduation to line up with the zero index. For instance, when the plane turns left the magnetic course dial and the directional gyro pointer along with the ARK-5 pointer swing to the right, i. e. the pointers move in the same direction from the zero index. This is the basic difference between the readings of the GIK and the readings of independently operating DGMK-3 and ARK-5, in which case the ARK pointer and the small aircraft image on the DGMK-3 moved in opposite directions.

The gyro-induction compass with combined indicator simplifies considerably the operation of the aircraft under adverse weather conditions. The landing approach techniques remain the same as when using the ARK-5. Having covered the computed time $t_{g.p.}$, the pilot turns the plane on a landing course in such a way that the pointers of the ARK and the directional gyro (before coming within the range of the homing radio station it should be set on a landing course) would both line up under the zero index. This is achieved by selecting the correct bank when making the turn.

Pilots who train for landing approach with the GIK find certain unusual features in this operation, as for instance correcting errors on a landing course while breaking through a cloud cover from above. They must become familiar with these features in advance, even ahead of training flights, in order to avoid navigation errors and to master the use of a gyro-induction compass more quickly.

Through my personal experience in making an instrument landing with the aid of a GIK, I have arrived at the following conclusions. Whenever, following a wide turn, the ARK pointer comes up against the zero index and the directional gyro pointer is to the left (exceeding the landing course - Fig. 1a) it is necessary to continue the turn to the right with a bank of 15-20°. At this time the ARK and the directional gyro pointers will begin swinging to the left of zero index. The moment the ARK pointer reaches a point midway between zero index and the directional gyro pointer (Fig. 1b) the turning is stopped and the aircraft continues on this course. The ARK pointer will continue to move on to the left; as it approaches the directional gyro pointer (which indicates the plane's alignment with the landing marker path, Fig. 1c) it is necessary to complete a left turn so that the zero index would line up with the pointers (Fig. 1d).

Fig. 1. Adjusting the plane's heading to align it with the landing strip whenever the plane's course exceeds the landing course.

Fig. 2. Aligning the plane with the landing strip when the plane is on the landing course.

If on the other hand, after recovering from the turn the pointer of the directional gyro lines up with zero index (the plane is on a landing course) and the ARK pointer has shifted to the left (Fig. 2a) then the plane must be turned in the direction of the deflected ARK pointer until it reaches a point midway between the zero index and the directional gyro pointer (Fig. 2b) and proceed on this course. When the pointers are close to each other (Fig. 2c) the plane must be turned in the direction of the deflected pointers until they are lined up with the zero index (Fig. 2d).

And what about the pilot who has to fight drift on a landing course? With separately installed DGMK and ARK the pilot, having determined the drift, heads the plane in a direction opposite to the drift so that the ARK-5 pointer and the aircraft image on the DGMK-3 would swing in opposite directions, away from their zero positions at an equal angle. If this angle remains steady during further flight, this fact indicates that the aircraft is not drifting off the landing course.

When fighting drift, the readings of the ARK and GIK directional gyro pointers will differ completely. The drift of the aircraft will be determined by the deflection of the directional gyro pointer from its zero index while the ARK pointer is held at zero. When the aircraft is drifting to the right of the landing course the directional gyro pointer also deflects to the right, in contrast to the action of DGMK-3 where under identical conditions the plane image swings to the left. Having determined the drift it is best to make the error correction by placing the plane on the landing course first, and then to start combating the drift by selecting the angle for completing the plane's turn in a direction opposite to the drift.

Whenever the directional gyro pointer swings to the right it is necessary to swing the plane in the opposite direction in such a way that the ARK pointer would also swing toward the directional gyro pointer. If the angle of turn is small then the ARK pointer will lag behind the directional gyro pointer which indicates the necessity of swinging the aircraft at a greater angle. If on the other hand the ARK pointer rapidly moves toward and overtakes the pointer of the directional gyro, this means that the lead angle is too great and it should be reduced. Whenever the lead angle is correctly selected both pointers coincide and the angle between them and the zero index remains constant (Fig. 3).

Fig. 3. Selection of lead angle when overcoming drift on a landing course.

It is essential to keep in mind that when selecting the lead angle for drift, the additional turn of the plane is in the opposite direction to the deflection of the directional gyro pointer. In contrast to the readings of separately installed instruments DGMK-3 and ARK-5 on the combined indicator both pointers swing in the same direction from the zero index during the selection of the lead angle.

Pilots accustomed to piloting aircraft with separately installed DGMK-3 and ARK units will be unfamiliar with the readings of the combined indicator. In order to master this instrument more quickly it would be well to sketch on paper a number of gyro-induction compass readings corresponding to various plane positions on a landing course. In addition it would be desirable to do the same for a number of straight-in approaches under normal weather conditions.

The approach pattern of the "big square" remains the same. But because the combined indicator has three additional indexes, the landing approach by the above method is facilitated under adverse weather conditions.

NIGHT BOMBING OPERATIONS UNDER ADVERSE WEATHER CONDITIONS

Military Navigator First Class Maj. P.A. Vazhnev

Night flights even under normal weather conditions represent a fairly difficult kind of training and require firmly established habits, endurance, special precision and teamwork from the crews. Bombing under these conditions, even in good visability, is much more complex than in daytime, because of the difficulty in locating the target. At night the strain for the crew members is greater, a factor which also may influence the quality of piloting and the accuracy of bombing.

On night flights all the members of the crew have to work under weak artificial lighting of the cabin and the instruments. This obliges the crew to make all the necessary preparations and calculations beforehand, so as to reduce to the minimum the amount of work to be done in the air.

Because of the specific features of nighttime diffusion of radio waves the precision of navigational computations using radio direction finders and the hyperbolic system of air navigation decreases.

The bomber crew encounters even greater difficulties if the night bombing mission is carried out under adverse weather conditions. To the specific features of night flying are added all the difficulties characteristic of flying under adverse weather conditions: piloting by natural horizon even under clouds is completely precluded, one has to navigate only by electronic or celestial aids, and to sight only with the help of electronic means.

While preparing for a night bombing operation under adverse weather conditions the navigators of our unit, who operate radar bombsights, pay special attention to the choice of easily visible radar check points which guarantee a sure approach to the target and to the study of the specific features of the target and the check points located near it, and their reflection on the bombsight scope.

In addition we work out beforehand the ways of using the radar sight for detecting dangerous weather phenomena. We also plan in advance the use of possible alternate navigational aids for different stages of the flight in case of unfavorable weather changes.

For successful accomplishment of night bombing missions under adverse weather conditions, ground preparations and training are of great importance. The navigators of our unit practice all operations with instruments and cabin equipment in such a way as to be able to operate "blind" in the air, thus using a minimum of time.

The navigators also practice on a trainer the order and ways of determining navigational and sighting data, and memorize the sequence of operations to be performed on a bomb run. In the light of my own experience I can state that one cannot expect success in night flights under adverse weather conditions without pre-

liminary painstaking training.

In our sub-group while practicing on a trainer we take into account the errors committed in the preceding flights. Thus, during one of the flights navigator M. I. Mezentsev made an error sighting in range. He failed to correct on the target the previously determined sighting data. Naturally this affected the quality of his bombing. So while preparing the next flight we helped the navigator to acquire sighting in range habits with the instruments on the trainer.

It is well known that precise computation of the wind is one of the conditions for efficient bombing. There are several ways of determining the wind under adverse weather conditions by means of the airborne radio technical equipment and the ground equipment. We generally determine the wind with the help of radar sighting of the radar check points. However, in order to determine the wind accurately, the crew uses several mutually controlling means. How important this is, will be seen from the following example.

During a night flight under adverse weather conditions, I divided the remaining leg of flight to the target into three parts. On the first segment, after having determined the wind, I calculated its speed. It was equal to 100 km/hr. On the second segment, while approaching the target, I noticed a sharp change in ground speed. This prompted me to check the wind data. In order to make sure of the change in the speed and direction of the wind and get its real value for the target area, I continued checking it throughout the second segment in relation to the base and time. Having established the ground speed I determined the drift angle, and on the basis of these data got the exact wind vector. The wind speed turned out to be 280 km/hr.

On the third segment I verified again that the speed of the wind had greatly increased. Checking it, I set it on the bomb sight and with these latest data began the bomb run. The results of bombing were very good for the wind in the target area had been determined pretty accurately.

No less important condition for good bombing is the exact timing of the bomb run. In order to cope with this problem, the crew has to check regularly the range and direction of the flight course. The sooner we spot the target on the scope, the more confidently we operate on the bomb run during sighting. Besides precise target approach enables the crew to see the target well in relation to other check points and the configuration of the blip itself as it had been memorized by the navigator during the preflight preparation.

The sooner the navigator spots the target the more time he has for checking sighting data (the drift angle and dropping angle). In spotting the target, let us say, at SR (slant range) = 120-140 km, the navigator will have enough time to measure the wind vector on the target itself by calculating W by base and the drift angle by computer.

The navigator's skill in "connecting" the target with other typical and radar check points is a guarantee for the timely detection of the target and precise approach to it. Going by the check points the navigator can confidently note on the scope the location of the target. For this purpose we always prepare a special map larger in scale than the flight chart. On it we make the necessary lay out and mark all the check points which will enable us to determine the location of the target on the scope. This is specially important while flying over an area with few check points.

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Not long ago our crew had to fly over an area with few check points. Before the flight the necessary radar check points were marked.

In approaching the target area, I gave the commander the course - 325°. At the initial point of the bomb run I started the stopwatch. As I had made all the necessary marks on the map beforehand, I had only to watch the time carefully. At every moment I knew the distance to the target, and when it should appear on the screen. And I actually spotted it at a distance of about 70 km.

However, to be doubly sure, I had to check my calculations with the help of other means. On my right, at about 50 km. distance, appeared a radar check point anticipated by me previously. By connecting the target light to this point I made sure that the plane was approaching the target and not some random blip. Then I pinpointed the heading of the course by the configuration of the target itself. All doubts were dispelled. Having made a precise target approach, I was able , in good time, to sight the target in direction and in range.

But there are times when crews overshoot the target or detect it too late. The navigator lacks time to accomplish the sighting in direction and range. This happens most often because the crew had not prepared for flight adequately.

Once one of our crews was carrying out a night assignment under adverse weather conditions. While approaching the target the navigator became engrossed in taking wind readings and neglected to control the heading. As a result of the change in wind the plane drifted off course 30 km. Discovering the error the navigator began searching for the radar check point which, according to his calculation, had to be on his left. While he was trying to read the situation the check point was left behind.

An additional maneuver for target approach became necessary, as a result of which the navigator had to alter the previously planned direction of approach. This in turn produced difficulties in further control of the flight course and changed the configuration of the target blip on the sight screen. In order to clarify the situation the navigator had to spend extra time, and as a result the sighting was delayed and he could not drop the bomb. The plane overshot the target. And all this happened because an accurate and timely bomb run was not ensured beforehand.

Let us now analyse the problem of checking the sighting data in aiming in direction and in range.

Here is a typical example. An aircraft with young navigator, A. P. Dokukin, was approaching the target. Because of inaccurate drift data the target slipped off the lubber line to the left during the bomb run. The passive attitude and poor ground training of the navigator became evident: he corrected the target course only by lateral control without using the drift correction control at all.

As he approached the target its divergence from the lubber line became greater. More time was needed for changing the course, which resulted in sharp handling of the controls, especially the drift correction controls, and in bumpiness. The results of bombing were very poor.

In order to achieve a high degree of accuracy in sighting in direction one has to effect it with the automatic lateral sight turned on: then the autopilot is more stable and the piloting smoother. Moreover, experience shows that an error in "BURP" (bomb run course error? -Tr.) rarely exceeds three degrees before bombing. Therefore for checking the lateral sighting the drift correction control suffices completely.

In starting the bomb run the "ABN" and the automatic synchronizer are turned on, and the sighting data for the bomb run computed.

Before taking over the controls, I check the sight. It has to be precisely positioned level wise especially in relation to latitude. During "search" I line the plane into the target taking the angle of drift into consideration (it is better to let the pilot line up the plane). After this I take over the controls and, if necessary, correct the aiming in direction.

While executing the lateral sighting one should strive to maintain stable flight attitude over the bomb run. One should bear in mind that it is better to make one or two accurate turns in one direction (the direction of sliding of the target) than make five or six turns now to the left, now to the right.

It is very important that all the crew should participate in sighting in direction. Our crew commander always checks the flight attitude by the course indicator. If there is a deviation of the pointer, which sometimes happens during the flight especially if the autopilot is not stable, the pilot notifies the navigator not to mistake the sliding of the target from the lubber line for an error in drift angle and not to start correcting the lateral sighting. In that case the navigator corrects the position of the target in relation to the lubber line only with the turn control stick.

During sighting in range it is necessary that the navigator should have accurately computed altitude H_{true} and the speed V_{true} showing on the computer. During the preliminary synchronization the navigator determines the ground speed W from the bombardier's panel. He compares it with the speed received from the computer and determines the accuracy of the sighting angle worked out by the sight. Now he knows whether he must correct the sighting angle φ during the basic synchronization.

In order to make the altitude set on the computer correspond to the altitude over the target our navigators always compare these readings in passing from the preliminary to the main synchronization. The true altitude over the target is controlled with the help of a radio altimeter, in order to avoid an error, which in turn may result in faulty sighting in range during the bomb release.

During both daytime and night bombing exercises, the position of the target blip relation to the sighting marker during the synchronization and the bomb drop, is also important. I refer to my own experience. At the moment of synchronization I keep the target blip on the tangent with the vertical line. Then, after opening the bomb doors, I place the target blip on the cross hair of the horizontal and vertical lines of the light filter. At the same moment I center the sighting marker altitude wise relation to the cross line in such a way that when the target blip is introduced into the cross hair, half of it would be submerged in the sighting marker. I stop the basic synchronization 7-10 degrees before the indexes coincide and then hold the target relation to the sighting marker only by means of the sighting control knob. This method of sighting in range always gives good results.

Thus, if the crew works harmoniously, follows strictly all the rules of navigation, and controls systematically the range and direction of the flight course, it will be able to approach the target on time and strike it with accuracy at night and under adverse weather conditions.

RADIO AND RADAR WEATHER RECONNAISSANCE

Engineer Major A. S. Smirnov

The weather information available to the meteorologist before the start of flights under complex conditions frequently does not make possible a sufficiently accurate description of weather conditions in the region of the projected flight. To obtain the necessary supplementary data aerial weather reconnaissance is scheduled.

The weather reconnaissance crew has to determine a large amount of data concerning weather conditions, and not only establish the actual condition of the weather but also investigate, as far as possible, the nature of its changes. They have to ascertain the altitude of the lower and upper limits of the cloud cover; its stratification according to height; zones of icing and turbulence; visibility under, in and beyond the clouds; and dangerous weather phenomena (thunderstorms, fog, low cloud cover, precipitations of all kinds.)

In the article "Our Experience in Meteorological Support of Flight Under Complex Conditions", which appeared in No. 11 of last year's issue of the journal "Vestnik Vozdushnogo Flota", the authors described in sufficient detail, aerial weather reconnaissance, and there is therefore no need for us to repeat. The purpose of the present article is to clarify some aspects of the utilization of radio stations in organizing aerial weather reconnaissance as well as during the flights.

In the air force units insufficient attention has been given to radio weather reconnaissance up till now, and in individual air force elements such reconnaissance has not been carried out at all. In our unit, for instance, the opinion prevailed that radio weather reconnaissance was not particularly useful for actual flight support. This opinion, however, soon had to be abandoned. And now it has already been proven that radio weather reconnaissance, if set up correctly and in a well thought out manner, gives exceptionally valuable material which supplements information about the weather.

It is well known that in order to solve successfully the problems confronting it, the weather reconnaissance crew must, prior to the flight, make a preliminary study of the weather situation which can be defined in greater detail with the help of radio aids.

A general picture of the distribution of storm nuclei and precipitation zones is formed through observation of the signals reflected from the meteorological "targets" within the radius of action of a radio station. In the same way, determination is made of the coordinates, area and form of the clouds under observation, the direction and speed of their movement and also of the nature of the meteorological phenomenon.

In our work we make systematic use of radio stations for weather observations,

especially when flights under complex weather conditions are planned.

Usually an hour before the weather reconnaissance mission takes off the operations officer organizes a radio weather reconnaissance. The weather service officer or a meteorologist on duty is at the radio station or at the mobile PPI unit. All meteorological "targets" reflected on the PPI screen together with the direction and speed of their movement are plotted on a circular weather chart or on a storm chart.

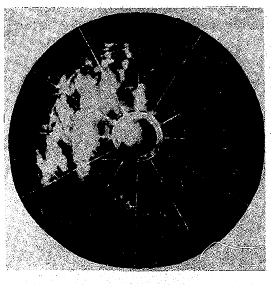

Fig. 1. A powerful cloud formation was recorded on the radarscope. This system was connected with the passing front.

Next, on the basis of the latest weather charts and radio reconnaissance data, the operations officer together with a meteorologist on duty and the reconnaissance crew determines the exact weather situation in the flight area. The course of the reconnaissance plane is then plotted according to their forecast. Only after all this preparation in which, as we have seen, radio weather reconnaissance plays a far from inferior role, does the weather reconnaissance crew take off. After completion of the reconnaissance mission, the meteorologist on duty gives an exact weather forecast for the flight period, reports it to the operations officer and informs the flight crew about weather conditions.

Let us examine the way weather reconnaissance was organized and carried out on one of the flying days in our unit.

The weather for the flight period was influenced by an occluded front which moved from the west with a speed of 20 to 30 km/hr. Before the take off of the weather reconnaissance plane the following was observed over the airfield: 10-point cloud cover with lower boundary at 2000 meters, haze, visibility of 8 kilometers, wind south-east at 6 meters per second. Deterioration in the weather, according to data of the synoptic and circular charts, was expected by 1300 - 1400 hours.

The radio weather reconnaissance which had been carried out confirmed the presence in the west of a powerful frontal region - some 80 - 90 km. from the airfield. It was also determined that this front was moving with a speed of 20 - 25 km/hr.

Capt. P. M. Sochinskiy, after studying the preliminary data on the weather situation, took off on a reconnaissance mission. He reported that there was a 10-point cloud cover over the airfield, its lower boundary at 2100 meters, visibility at 6 - 8 kilometers, at a distance of 40 - 50 kilometers west of the airfield, the cloud cover descended to 1500 meters and with visibility at 4 kilometers there was precipitation. He also reported that at 90 to 100 kilometers from the airfield the cloud cover was descending to 600 to 300 meters, and that the upper boundary of the cloud deck was at an altitude of 9500 meters.

On the basis of the radio and aerial weather reconnaissance, the meteorologist on duty, Major A. K. Prokudin, Engineer Service, concluded that the weather in the area of the airfield would deteriorate not by 1300 - 1400 hours, as had been previously announced, but as early as 1000 - 1200 hours as was subsequently confirmed. Fig. 1 displays the position of the cloud cover on the PPI screen two and a half hours after the weather reconnaissance. Fig. 2 display was made at a time when the cloud cover over the airfield had descended to 200 - 250 meters and visibility had decreased to 3 - 4 kilometers. It shows clearly that the situation had changed considerably.

Before night flights radio weather reconnaissance precedes in exactly the same way, the take off of the reconnaissance plane. For example, one of the days preceding night flights, the weather in our area was influenced by a secondary front moving from the north-west and subsequently by the movement of an occluded front from the west.

Prior to the take off on a weather reconnaissance mission the situation over the airfield was observed to be as follows: a 6-point cloud cover with lower base at 800 meters, visibility at 10 kilometers, and wind west at 8 - 10 meters per second. One hour before the take off of the reconnaissance plane, it was established in the course of radio weather reconnaissance that to the west of the airfield, at a distance of 110 - 120 kilometers, there was a powerful cloud center moving towards the airfield with a speed of 45 - 50 kilometers per hour: and to the north-east at a distance of 50 kilometers there was another cloud center moving southeast away from the airfield. Thus, one could expect over the airfield a powerful cloud formation from the west, increasing to the point of solid over-cast, lowering of its base, deterioration of visibility, etc. This was reported to the operations officer and the reconnaissance crew who had taken off.

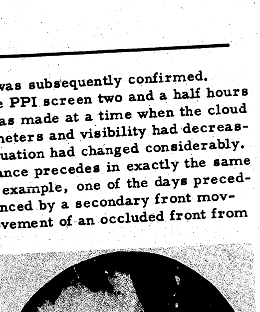

Fig. 2. The same cloud formation some time later, when the cloud cover over the airfield had descended to 200 - 250 meters, and precipitation had started.

At a distance of 50 - 60 kilometers west of the airfield, the weather reconnaissance pilot detected the beginning of a 10-point cloud cover with a base at 1500 meters. At a distance of 70 kilometers the cloud cover was descending to 600 meters, there was some precipitation, and visibility was decreasing to 1 - 2 kilometers; the cloud deck reached 4500 - 5000 meters with individual caps of 6000 - 7000 meters. Simultaneous observation of the displacement of this cloud cover on the PPI screen enabled us to ascertain that its northern portion should touch the airfield. The forecast was confirmed.

Thus, properly organized radio and aerial weather reconnaissance (which supplement each other) make it possible to determine under any conditions the nature of changes in the weather situation and the time of deterioration in the weather, as well as to give due warning of dangerous weather phenomena.

It is also advisable to carry out weather reconnaissance during flights by means of radio stations available in groups and units. Besides, this type of weather reconnaissance makes it possible to reach a final decision regarding flights.

In practice it works out as follows: the equipment is at the flight line and everything is ready for the flights. But at this time, the weather deteriorates sharply and the flights are called off. As yet, the meteorologists cannot always predict all changes in the weather. However, such changes as the beginning precipitations can be predicted by means of the data provided by the radio stations.

Let us cite one more example. Before the night flights, according to the information which the engineer-meteorologist had at his disposal prior to radio reconnaissance flight, radio reconnaissance was organized, during which it was determined that 100 - 120 kilometers west of the airfield there was a powerful cloud formation center moving east with a velocity of 20 - 25 kilometers per hour. This meant that the weather in the area of the airfield would deteriorate sharply in 4 - 5 hours. Radio weather reconnaissance in this case served as a deciding factor which made it possible to give a correct forecast. On the basis of this, the commander cancelled the flight. The sharp deterioration in the weather, which occurred soon afterwards, confirmed the timeliness of such a decision.

The use of radio stations for weather reconnaissance and observations of the weather situation during flights, are very helpful for the meteorologists intheir work to insure flight safety. By use of the data obtained from radio weather reconnaissance, it is possible with great accuracy to determine the areas with dangerous weather phenomena and the direction and speed of displacement of air masses. With careful observations, and sufficient experience it is also possible to determine the state of a cloud center, whether it is dissipating or growing.

It is characteristic that if a cloud system does not contain elements which cause sharp changes in weather, the cloud cover is not detected on the PPI screen. Usually in such clouds the flight is smooth, without bumpiness and icing.

In the winter time, especially during snowfalls and these usually occur at definite intervals - it is possible through the use of radio weather stations, to predict the periods of these snowfalls very accurately. Consequently, it is possible to give due warning to the operations officer and flight crew and to indicate the time when a safe landing is assured.

The groups and units have every opportunity to employ radio stations for meterological purposes. The more so since the use of these stations for weather reconnaissance does not at all mean that these stations are being switched over entirely to the observation of weather elements. The weather reconnaissance can be conducted at the same time that the stations carry out their primary task - observation of planes in flights.

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"Our Experience in Meteorological Support of Flights Under Complex Conditions"

ON IMPROVING THE METHODS OF FLYING INSTRUCTION IN THE AVIATION SCHOOLS

Captain B. N. Voronov

Nowadays every adequately trained pilot flies under complex weather conditions and at night. Many pilots master flight at supersonic speeds; they conduct combat training missions in the stratosphere, and carry out maximum range flights.

Under these circumstances the units expect to receive from the aviation schools, thoroughly trained cadres of young men, who could become first rate pilots as rapidly as possible. Obviously, in order to achieve this goal it is necessary to improve constantly the methods of trainee instruction in the aviation schools.

The main elements of flight technique have been set forth in the respective documents which serve as a guide for both the combat units and the schools. Still there is a lack of agreement on some questions. Consequently, a young pilot coming out of an aviation school into a combat unit faces a number of difficulties. He has to learn all over again, so to speak. This entails a greater familiarization-program load, unnecessary expenditure of resources, a longer term required for integrating the young air personnel. In my opinion this happens because there are still no well established channels for the exchange of experience between the training establishments and the line units.

I have checked out at our training school, for example, twenty-one young fighter-pilots in La-9 and MiG-15, but have no further information about their subsequent activities. How do they fly? What are their shortcomings? What should I, as an instructor-pilot, stress in teaching new trainees? All these questions have remained unanswered because information from the line units reaches the aviation school rarely or not at all. The instructor continues using the same methods of instruction.

The instructor personnel of an aviation school has very slow turnover. New members joining the staff are drawn either from among the pilots of training units or from among the young graduates. This setup unfortunately fails to introduce anything new and presents no opportunities for becoming familiar with the experience of the line units.

The line units are in a somewhat different position. There the instructor personnel is made up essentially of active pilots with wide experience and many flying hours. The line units are the first to master the new types of combat equipment, and they are the first to start flying under complex weather conditions. All this brings many new ideas to flying techniques and methods of instruction. These new ideas are just what the schools need so urgently.

Right now I am serving in a line unit and as a former instructor of an aviation school I am especially aware of how long it takes for new developments, originating in the unit, to reach the school. Apparently not all the schools are sufficiently concerned with benefiting from progressive experience or with becoming familiar with

new flight training methods, even though all this is extremely important.

Let us cite the following example. In 1955 in my flight section, I worked with two graduates of one of the aviation schools. I had no special criticism to offer as far as their flying technique was concerned. They were quickly integrated: now they are flying MiG-17's and are successfully forging ahead. But in the beginning both pilots gave evidence of the same error when flying UTI MiG-15. They failed to operate properly the rudder, and also the brake during the landing run: they pushed the rudder pedal too far forward to keep the plane straight and thus caused bumpiness. The actions of both pilots were similar to those of a pilot of a Yak-11. As it turned out later, their former instructor had begun training cadets on a jet aircraft for the first time back in 1954, and before that he himself had flown a Yak-11. It must be assumed that he had carried over his Yak-11 flight technique to a MiG-15 passing on to the cadets his own faulty piloting technique. At an airfield with a wide landing strip such an error was not especially noticeable and therefore the senior commanders could not point out the error to the young instructor-pilot.

Thus in the line unit it became necessary to drill over again that which the pilot should have mastered perfectly at the aviation school.

Perhaps this example is not so typical and that the instructor has by now eliminated this fault in his piloting technique. But it is also possible that he is still committing this error. If appropriate signals of this kind could reach the aviation schools how much they would help the instructors improve their work and raise the quality of training of the graduating pilots! It is absolutely necessary that a systematic exchange of opinions on the quality of cadet flight training be established: it will assist greatly in the overall process of pilot training.

It seems to me that the old tradition which was in effect during the Great Patriotic War should be revived. At that time the pilots of the aviation schools were assigned to line units in order to gain experience. After being in the unit for two-three months they would become familiar with the special features of flying technique, methods of training, the routine of preliminary and preflight preparation, organizing a flying day and the specific aspects of combat flying. Later on they made use of all that was necessary, useful, and helpful in their work. Why even now we could organize detached service for good pilots who are methodology specialists in our schools, so that they could study the special features of flight work in the line units and help disseminate the wealth of experience accumulated there during the post-war years.

A most urgent demand for the above exists in connection with mastering the new equipment and the new possibilities in piloting modern combat aircraft. The technique of piloting changed particularly after our pilots had begun to master flight under complex weather conditions. It is precisely here that new features appeared in the technique of piloting, and every young pilot coming from the aviation school encounters them.

For instance, when making a landing, a fighter pilot in the line unit maintains a shallower glide angle than at school. This can be explained as follows: the straight-in landing approach by the GCA system results in a long glide. With a decrease in altitude the angle of glide decreases. As a result the pilot's view of the landing markers and the direction of his ground view change. Such a gliding angle is utilized in circuits and bumps. This can easily be seen when a pilot, having completed the third turn at the specified point and the fourth turn at prescribed altitude, brings the aircraft down to an altitude which corresponds to the glide angle for the GCA system. During the very first training circling flights, the young pilot is reprimanded (his glide angle is too steep). This is the beginning of his relearning, because with a shallower gliding angle the calculation is different, diversion of attention alters, and the procedure for speed and rpm control changes. This can be avoided by teaching the trainees to use a shallower gliding angle during their combat training phase of instruction (i.e. in the terminal phase of the flight program).

Furthermore, pilots flying under adverse weather conditions grasp a number of principles which greatly facilitate the technique of flying in the clouds. Let us consider, for example, how to divide one's attention among the instruments - the speed indicator and the tachometer. The pilot sets the specified rpm for the given flight conditions and thus easily maintains the necessary speed. But this skill cannot be mastered all at once. It is not so simple to establish the prescribed speed if the rpm is to be adjusted to the speed. The pilot has to keep on either increasing or decreasing the rpm. Whoever has gone through a training program under complex weather conditions will certainly recall such experiences. But on a jet plane, it is difficult to select the correct flight aspect by this method, because of the plane's great inertia and because it is not easy to "catch" the operating condition of the engine required for the specific speed. Therefore, if one knows in advance the rpm needed for a given speed, it is easy to maintain it, but a new element is added to the diversion of the pilot's attention, namely "speed - tachometer." Unfortunately this fact is not given due consideration in the initial flight training of cadets in general and when training on jet aircraft in particular.

Let us take the experience gained from training at the aviation school. A cadet flying a Yak-18 and a Yak-11, maintains his speed by the speed indicator, selecting the necessary rpm, sometimes without reference to the instrument readings (manifold pressure and tachometer). Why even the instructor does not always require this of him because it is not provided for in the outline for diversion of attention in level flight. This outline is as follows: cowling - horizon - speed - bank - angle of turn, and in addition the course of planned flight. The same applies to climbing and gliding.

With these set habits in the technique of piloting and diversion of attention, the cadet transfers over to a jet aircraft. If the fighter pilot were training only for flights under simple weather conditions, this preparation would be quite adequate. But the ultimate goal of a fighter pilot's training is the ability to carry out missions under all possible conditions. Thus the following conclusion is indicated: a pilot must be trained to fly under complex weather conditions beginning with the aviation school. Or rather typical situations in the division of the pilot's attention should be stressed constantly throughout the training process which will then greatly facilitate his preparation for such flights. There are opportunities for achieving this.

While still at the aviation school the cadets must be taught to divide their attention between the speed indicator and the tachometer as well as when flying under complex weather conditions. The order in which attention is distributed should be changed to the following sequence: cowling - horizon - speed - rpm. This will but slightly complicate the training procedure, while the benefit will be great.

The same can be said about working with a watch. While flying under complex weather conditions, a pilot must know how to make use of it. This is particularly necessary when making an instrument landing approach after passing the distant homing station, when carrying out flights by using the method of two 180° turns, and in a number of other instances, not to speak of control of flight time, especially at low altitudes. If a pilot has hitherto worked but little with a stop-watch and its calibration and with a flying-time knob and its scale, it is difficult for him while flying in the clouds, to shift his attention from the other instruments to the stop-watch and to reckon the elapsed time from it. The pilot may not manage to set the stop-watch immediately upon passing the distant homing station or glide path. Under these conditions each wasted second threatens flight safety.

It might seem that working a stop-watch and taking its readings would be a very simple matter, but actually the operation can be rather complicated if the pilot has not developed the necessary habit. Obviously at the aviation school not enough attention is given to work with the watch. A trainee rarely uses the time scale and even more rarely the sweep-second scale (only a few flights on a planned course, when he times a leg of flight by the sweep-second scale). Of course this amount of practice is not sufficient to develop fixed habits. Besides, as a rule, the instructors do not give a rated evaluation for work with the stop-watch.

We should note one other flight characteristic peculiar to aviation cadets as compared with a young pilot of a unit. This concerns the fact that the airfields of most aviation schools have dirt covers and consequently broad landing strips, whereas the line units are based on airfields with narrower concrete or mat runways. This factor has a bearing on the landing training of cadets. Unquestionably it is much more difficult to glide onto the middle of such a runway than onto the wide runway of the training school airfield. The pilot must be more attentive. One small error (bank, belated compensation for drift) is enough for the plane to glide down off center, thus leading to undesirable consequences. It is particularly difficult for the young pilot to keep the plane on course while leveling off and holding, when the lateral displacement of the aircraft (if such occurs) is checked by ground contact.

During the first practice training flights, the young pilots usually encounter this difficulty immediately. They are not able to divide their attention sufficiently so as to control the accuracy of approach and determine the distance from the ground. As a rule, the first attempts at precise landing approach are accompanied by a poor touchdown when landing is made after leveling off too high or zooming. Why does this happen? It is quite obvious. At the wide airfield of the school, the control of the precise approach and letdown until the nose wheel touches the ground, is relaxed. As a result the cadet develops a fixed negative habit. It goes without saying that the training must follow the principle of proceeding from the simple to the complex. Nevertheless, I feel that while the cadet is still in the aviation school, the landing conditions must gradually be made more complex to simulate those existing in the regular units. After all, it is not difficult to mark out on the dirt surface with lime, squares of sand, etc., a strip 60 - 80 m wide.

There is one other unusual feature confronting a young pilot who is beginning to fly from an airstrip of limited dimensions. It is the element of maintaining the required direction during the landing roll. The fact of the matter is that deflection of the plane on a concrete or mat runway is perfectly obvious. The pilot reacts to the slightest direction deviation of the plane by braking. This leads to an incorrect braking procedure and jerkiness of the plane during the roll. Both of these facts have an undesirable effect on the brakes and landing gear. Statistics show that the number of untimely brake failures and tire wear is greater, as a rule, in squadrons where young pilots fly, than in others. This lends support once more to the idea that cadets should be trained at the aviation school on a runway approximating standard dimensions.

We would like to dwell on one other matter as well. The standard practice at the aviation schools requires a cadet to fly solo in the training zone the very same day he receives a flight check in a jet aircraft for some new acrobatic maneuvers. If there is a break of more than three days between the flight check and the solo flight employing the new acrobatic maneuvers, the flight check is repeated.

In the event that the cadet already flies solo in the training zone, he is allowed between flights a maximum lapse of five days and up to eight days toward the end of training. If the lapse is greater he is given another flight check. This routine of zone flight training in jet aircraft has been prompted by practical experience, and so far it has been justified.

The procedure in the line unit is different. There, for instance, pilots 3rd class, or those of equal status, are checked for piloting technique once every three months. But such a practice is not suitable for young pilots coming from the aviation school. A prolonged break between flights has very undesirable effects on the young pilots while they are becoming adapted to the flying routine of the unit. The breaks between the flights into the zone (especially in the northern regions of the country) often last longer than a month. Despite this fact the young pilot is allowed on a training flight, because officially the time limit on permitted breaks has not been violated.

We feel that a somewhat different procedure should be adopted for flight personnel in their first year of service. If the young pilot has more than a fifteen day break between his training flights in the zone, he must be given a repeat flight check for the given maneuver.

The urgent task of each commander is to improve continually the training methods used in teaching the cadets in the aviation schools as well as the pilots in the line units, in keeping pace with new developments in aviation. The more successfully this task is solved the better the results we will achieve in the combat training of flying personnel.

A NEW DETACHMENT OF MILITARY PILOTS AND NAVIGATORS, FIRST CLASS

Recently the ranks of military pilots and navigators, first class, were reinforced by a new detachment of officers who had achieved a high state of proficiency in combat training. This superior rating has been awarded to A. P. Sugatov, Ye. A. Serebryakov, N. K. Zakharov, I. A. Kolkov, M. I. Shamshurin, N. I. Kireyev, Ye. S. Virchenko, and many other officers from diverse services and age groups. The

senior officers enriched by combat experience and the very young officers were all congratulated by their comrades-in-arms on their being awarded the highest rating.

Each new military pilot and navigator first class has his own life history and his own plans for the future. Fighter pilot S. D. Gorelov recently took command of a group and within a short period achieved noteworthy success in the combat training of his subordinates.

Officer V. M. Drygin left for a military academy to round out his knowledge in the field of theory. Officer V. A. Vasin is well-known to fighter pilots as an excellent instructor and a good methodologist, who had trained many pilots to fly under complex weather conditions. Officer Yu. I. Kazak has an important creative task before him. Together with other pilots he will take active part in further perfecting techniques for combat application of modern fighter planes.

A. F. Anikin, a young pilot in the bomber unit, is quite a newcomer to the Air Force, but by persistent work has mastered in a short time the difficult and extensive program of flight training and combat application of bombers under complex weather conditions and at night.

At the last inspection check out navigator I. G. Kuzmichev made an excellent showing. He had successfully accomplished a high altitude bombing mission on an unfamiliar bombing range under complex weather conditions. All his subordinates also carry out precision bombing at various altitudes, and are very skilled in the art of navigation.

Military navigator, first class, V. I. Sharopatyy upon completion of his studies at the Air Force Academy, joined a line unit. In one year he succeeded in perfecting his techniques in air navigation and combat application of a bomber. The knowledge he acquired at the academy helped him solve new combat training problems.

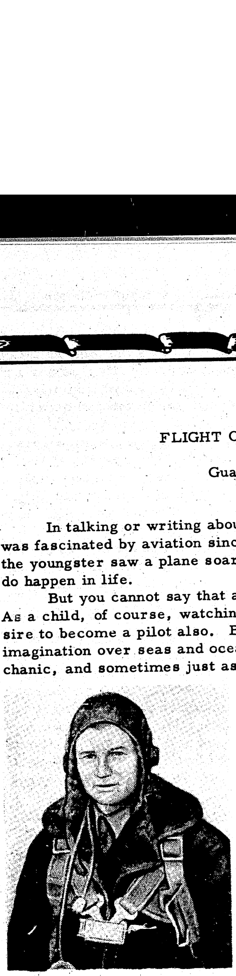
Military pilots and navigators first class - these are the remarkable cadres of the Soviet Air Force.

FLIGHT COMMANDER CONDUCTS FIRE

Guards Major A. N. Kiselev

In talking or writing about a pilot people almost invariably mention that he was fascinated by aviation since his young days. Already as a child, they'd say, the youngster saw a plane soaring in the sky, and his fate was sealed. Such things do happen in life.

But you cannot say that about fighter pilot Yuriy Grigor'yevich Mishchenko. As a child, of course, watching a plane in the air, he did sometimes burn with desire to become a pilot also. But on other days he would soar on wings of childish imagination over seas and oceans, sometimes as a skipper, sometimes as a mechanic, and sometimes just as an ordinary seaman - the more so because he was born and bred in Mariupol', where people were closely bound with the sea. And sometimes it seemed to him that it would be better to become a combine operator, a tractor driver or a car driver - the grownups have many professions which fascinate the child's imagination.



Yuriy Grigor'yevich Mishchenko

But life decided for him in its own way. His childhood was interrupted by the war. His father left for the front. On the day that Yuriy turned fourteen, and that was on the 7th of November, 1941, the 24th anniversary of the October Revolution, a date so memorable to all Soviet people, the boots of the aggressors were already striking the cobble-stone roads in the city of Azov shore, and curt orders in a strange tongue were resounding.

Adult worries and trials fell to the lot of the youngster, who together with his mother had to spend two long years under Fascist occupation. He saw and experienced a great deal. And it was at that time already that he made his first decision, not childish any more, but definite and firm, - to be like his father, like everyone who had enough strength to hold a rifle, to become a soldier and fight against the hated enemy.

When in the fall of 1943 the long-awaited Soviet Army came, Yuriy joined its ranks as a volunteer. And then started the long road of war until one bright May morning, when the last shot had sounded over the fallen enemy, until the day of victory.

As a tank driver in the Seventh Separate Guards Motorized Regiment in the Fourth Tank Army, Y. G. Mishchenko took part in the battles of L'vov, Dubno, Tarnopol', Sandomir, served in a reconnaissance platoon, reached Berlin, fought in Prague.

Medals "For Bravery," "For the Capture of Berlin," "For the Liberation of Prague", "For Victory Over Germany" on the youth's faded battle dress spoke eloquently of his having covered this first hard stage of his career honorably as fits a Soviet man and a soldier-guardsman.

Then soldier's fortune brought him to Bulgaria. There unexpectedly he met his father, a lieutenant-colonel in the Soviet Army, who passed by other roads - through Rumania, Yugoslavia, Hungary and Austria. The meeting was a joyous one. Father and son proved worthy of each other.

Mishchenko served in Bulgaria for almost a year. Then his superiors noticed that he had an exceptional artistic gift. In our country every talent is cultivated carefully, so Yuriy was advised to train himself seriously in the art of painting.

In 1947 he entered an art school in Kiev. But strange to say, although in two years he finished the school successfully, it was not this school but the air-club which decided his further fate. It was in this field that the former tank and later car driver, the man who had just received his artist-painter diploma, found a profession, a work which was his true calling.

The air club instructor, a man rich in wordly and professional experience, noticed in the lad qualities of a real pilot. And while training him he tried to develop those qualities in Mishchenko. He watched student-pilot Y. Mishchenko's first solo take off, first landing, first flying area flight. And when the training period was over, the instructor wrote of him in the service record book as follows: "Proved himself able, masters flying easily. Did not make a single rough landing on the UT-2. Feels at ease in any flight attitude, flies boldly and competently, approaches each problem seriously and conscientiously, has a gift for flying."

In this last remark the very essence of the man is very aptly noted - the man who disclosed his true calling to those who observed him, and lovingly, fatherlike, encouraged his growth. This was a real "pass to life." Further developments confirmed it fully.

Y. G. Mishchenko finished the Air Force training school as successfully as he did the air club. Here too his superiors remarked on this thorough mastery of the flying curriculum, his endurance in flights, his bold and sure piloting, that he always keeps his head under complicated conditions and makes decisions correctly and quickly.

Here we should qualify the statement. Not only in the first but also in all the subsequent evaluations of Mishchenko's work his high flying ability is always underlined. "He's a real pilot," say all the commanders in his air regiment. Does it mean that the man had some inborn ability?

Of course not. In our country pilots are called falcons. Not without reason did folk wisdom attribute to the pilots the prominent characteristics of these proud birds - courage, sharp vision, tenacity, lightning-speed reactions and exact timing. And yet, our pilots are more than falcons - they are men, Soviet men. Persistent, stubborn work enables them to master the complicated art of flying. They say that pilots are not born but made. Yes, they are made, if they love their chosen work and if, sparing no efforts, they march toward their goal day after day.

Step by step Sr. Lt. Y. G. Mishchenko approaches the top of flight mastery. From the first days after joining a combat fighter regiment, he attracts everyone's attention through his diligence, his capacity for solving any problems, by going to the bottom of all causes which escape the superficial observer's eye. Therefore all his work is of first quality, thorough, solid. Mishchenko gets unusually high pay, astonishingly high results in all elements of flight training.

A check of his piloting techniques shows convincing results. In the great majority of cases all observers of his circling and area flights give him the highest evaluation.

Though more than a year has passed since a certain flight mishap occurred, people still cite it when they want to describe the great piloting skill of officer Mishchenko. He was given an assignment to intercept a target. The pilot quickly took off, reached the assigned altitude and, following the commands from the GCI point, began already to approach the target area, when there was heard a sharp blow in the engine with subsequent engine vibration.

Sr. Lt. Mishchenko immediately reported the accident over the radio and having determined the best gliding speed for preventing too speedy a loss of altitude, turned to his airfield. Calmly and accurately executing the commands of the operations officer, he computed the precise data and then confidently proceeded to make a deadstick landing on his airfield. Both the pilot and the craft came out unscathed.

After checking the aircraft on the ground it was established that the engine had developed trouble for reasons beyond the pilot's control. The air group commander in a special order cited the proficient and courageous behavior of Sr. Lt. Mishchenko during complex flight conditions and rewarded him with a valuable gift.

Faultless control of the aircraft is that basic condition which ensures the success of every flight mission. From this stems his confidence in action, his ability to reach the right decision under the most complex situation and then to carry it out quickly and efficiently.

If we total up his combat-application flights for the last two years, for example, i.e.: high-speed target intercept flights, in daytime and at night, under normal and difficult weather conditions: air "battle" missions, attacks upon bombers, gun-camera and live ammunition firing exercises on air and ground targets, and express it conventionally by the number 100, then we get the following results: out of 100, only three times were the results below the established norms. On the other hand, 77 times Mishchenko got the highest evaluation, 15 times the grade "good," and only 5 times "satisfactory." These evaluations taken from his flying records, eloquently speak for themselves.

For a fighter pilot the basic, the most important part of combat training is his ability to destroy accurately a target in air combat. Aerial gunnery training is a very laborious process. Its culmination point, a kind of test of the pilot's combat maturity, is the live ammunition firing upon air target.

On a modern jet fighter the pilot's action during attack and firing on a target take up very little time. But such time is crammed full. In an air attack seconds crown all the pilot's hard, continuous, persistent work, his searching, his thoughts, the systematic ground and air training.

All this, without any exaggeration, applies to Sr. Lt. Mishchenko.

If a fighter destroys the target even with two or three shells, one says that his aiming is quite good. And if the number of hits is more than ten? And if half of the fired shells hit the target - what then?

Probably the answer would be that such a result was an accident. That's just what they said at first of Mishchenko's air target gunnery results. But accidents

cannot repeat themselves systematically. And it must be confessed that it was hard to believe at first that everything was done as it should be done, that the assigned firing schedule was observed.

But facts are more convincing than words. Of course while continuously searching for more efficient methods of target interception, Mishchenko could not avoid a few frustrations. Every experiment contains a certain risk. Once, when the aerial film revealed after having been developed, that out of four volleys only two could be marked on the record, the other two having been fired at too close a range, the squadron commander would not allow anything for the fact that Mishchenko was a well disciplined pilot and a good flight commander. He wrote on the interpretation card a remark about that ill-starred firing practice to the effect that the range was too close for flight safety, and in order that such a thing would not happen again imposed severe penalty upon the pilot.

Violation of the rules always brings penalty - such is the requirement of the military code. And so it also happened in this case. But this incident was mentioned at all only to point out that it never happened again in Mishchenko's practice. The results of his firing were more than excellent every time.

People began to show interest in Mishchenko's experience. One flying day a colonel from the group Headquarters came over and ordered the senior lieutenant to execute together with him a towed target firing exercise. Having recieved his assignment and prepared himself for firing, Mishchenko took off on his mission together with the inspector. When the two fighters approached the target area, the checking officer, in order to observe better Mishchenko's attack, took a position to the rear and below and gave a command to open fire when ready. After having executed the necessary maneuver according to the rules, Sr. Lt. Mishchenko closed in on the target and after sighting carefully, opened fire from the assigned distance and the established foreshortening of the target. One short volley ... and a splash of flame appeared on the target, showing that the shells had hit the metal parts.

The tow plane reported immediately a hit. Besides the pilots themselves saw the results of the attack. In the second attack Mishchenko, inspired by his success, sighted even better. The results surpassed all expectations. The fighter pilot showed once more his air sniper mastership.

What is the essence of Mishchenko's air gunnery proficiency?

He says that he started his work on improving his gunnery skills by studying the theory of gunnery, the possibilities of the sight. He did this not only as a duty during class work. He stubbornly tried to get to the bottom of all recommendations, to compare them with his own experience. He analyzed many formulas, many complex theoretical calculations. And he did all this only to convince himself that formulas in themselves do not give you anything.

But having said these words Mishchenko thought for a while and then clarified his thoughts thus: "these formulas don't give you anything except..." This "except" was the first revelation resulting inevitably from the theory. The first deduction at which the pilot arrived was as follows.

The semiautomatic sight ASP-3_H answers its purpose only if the gunner can hold for 1.5 - 2 sec. for the focal point of the sighting screen on the target at the fix. Time is needed to compute the necessary lead angle on the sight. But with today's speed of the target and the attacking fighter, holding the sighting point steady over the fix even for such a short period of time as 1.5-2 sec. is very hard, of course, if one observes the firing and safety rules.

What then is the solution? The solution, obviously, concluded Mishchenko, lies in not trying to hold the focal point of the sighting screen on the computed target position at all cost.

After many more checkings this conclusion was worded as follows: if target tracking is done with great (operational) overloading, then fire should be opened when the focal point of the screen is lagging with reference to the point of the computed target position; if, on the other hand, the overload while tracking is small(the firing position is taken up "sluggishly" - as the pilots say) - the fire should be opened when the focal point of the sighting screen is set almost on the nose of the target.

In following this procedure the pilot has time for aimed firing, as he is gaining the 1.5-2 sec. which would have been necessary for holding the focal point of the sighting screen in the computed position.

This is Mishchenko's way of resolving the problem of target-tracking errors.

However, it should be borne in mind that this method of coping with errors in sighting while intercepting with large and small overloading is very complex and out of reach for many pilots especially the beginners of aerial gunnery. One needs great proficiency and well established habits in order to be able to determine visually the exact moment for opening fire. Therefore, during the training period, the setting of the sight's central point on the computed target position and holding it there for not less than 1.5-2 sec. so as to determine the correct lead angle and thus ensure fire accuracy, still remains the main and the most dependable method in determining the moment for firing.

But where can one find the time required for sighting and firing? For this the pilot has to execute his maneuver correctly during the attack, and track the target with an optimum overload which enables the sight to work out the lead angle.

The problem of eliminating errors in sighting becomes still more complex in so far as the target has a relatively large dimension in length, but widthwise (height wise) is quite insignificant (70 cm). And if one considers the fire range (at least 300 m) then this value becomes really small. The slightest error in sighting and all the firing will be wide of the mark.

Having carefully studied the fighter's weapons adjustment chart and having compared the values of the ballistic trajectories of the shells above and below the sighting line, Mishchenko formulated his second conclusion: in order to avoid errors in altitude (depending on the fire range) it is necessary, during tracking and especially at the moment of opening the fire, to hold the focal point of the sight very accurately on the determined point of the vertical line, for its smallest oscillation along the vertical will result in the shells passing over or below the target.

The position of the focal point on the sighting screen in relation to the target depends on range, foreshortening of the fire and the plane's angle of bank. The focal point, as a rule, should be a little higher than the edge of the target.

It is unusual for a pilot to open fire with the sighting point above the target edge, and also very inconvenient to observe it against the sky, but having once decided to try it, Mishchenko became convinced that his calculations were correct. He became more and more convinced of it with every new fire practice. His ability to take into account the many mutually intertwining and interacting factors

determinating the results of firing, grew together with his experience.

In the final analysis the most important factor in air gunnery is the taking up of correct position at the initial moment of the attack.

How does Mishchenko operate in the air?

After coming abreast of the target with an interval of 100 m on the side of the approach the pilot makes a turn with a bank of 60° until the tow-plane approaches the outer limit of the aircraft's plane. Then the pilot starts recovering from the banking turn and takes up an identical-parallel course. This is actually the initial point of the attack.

The most typical errors in taking up the initial position are too great or too small an interval at the beginning of the turn. The pilot has to have a very sure eye. In addition, already the first attack will show the essence of the error. Therefore, in gunnery training exercises, Mishchenko generally makes his first approach only with the aim of determining his maneuver with greater accuracy and uses a gun camera for "firing."

If the interval was too great while taking up the initial position, one will have to pursue the target for considerable time during the first approach, and by the time it will appear on the gunsight at the required distance, the foreshortening will be too small, about 0/4, and it will be impossible to open fire because of too great an angular displacement of the target, too great an overload and too small a range.

In the first case the error is corrected during the second approach by decreasing the interval; at the moment of changing to a parallel course the tow-plane is visible at some distance from the plane of the attacking fighter. In the second case, during the second approach the tow-plane is covered by the plane of the fighter. At the same time it is assumed that the target is sighted at an angle of 90°, and that the distance between the target and the fighter at the moment of the latter's withdrawal from the first attack is approximately always the same.

Having made an error in taking up the initial position for the attack, pilots sometimes try to correct it either by "lying in wait" on parallel courses before starting the deployment maneuver or by starting the deployment maneuver at an angle greater than 90° in relation to the target course.

"Time lost for firing" - is the way Mishchenko describes it picturesquely. Neither by "lying in wait" for the target nor by increasing the angle of deployment to over 90° can one eliminate the error, for, because of the great angular displacement of the target there will not be enough time for normal sighting and firing. The pilot must take up the initial position in such a way as not to have a single idle second.

Perhaps, for this the approach will have to be repeated once or twice. Mishchenko himself sometimes had to make up to five "dry" runs during some of his gunnery training. And although this naturally enervated the pilot, still he never pressed the trigger button until he made a precise approach.

It is well known that a jet plane, because of its sweptback wings, has a tendency to crab in the horizontal plane, a fact which hinders sighting. Possible errors can be neutralized by increasing or decreasing the angle of bank just before firing. But at the moment of opening fire, in order to "pull up" more quickly, the focal point of the sight into the necessary position, the pilot sometimes causes slippage of the craft by too forceful pedal movements. If the beginning of slippage produces a sharp angular displacement, thus affecting the rotor of the sight's gyroscope, then a discrepancy arises in the angle between the sighting line and the shell flight trajectory during firing. This means that the target will not be hit.

That is why slippage at the moment of opening fire cannot be allowed and pilots are advised to hold the sight's focal point in place by banking the craft. However, it is impossible to avoid slippage entirely in the process of tracking and sighting. This is explained very simply. In manipulating the rudders evergetically, especially during sharp banking, the pilot, involuntarily, makes uncoordinated movements which in turn produce slippage. In the process of tracking and sighting the pilot is constantly watching the focal point of the sight and the gating of the target, and has no time for observing the flight instruments and eliminating involuntary slippage. But here knowledge and experience come to the aid of the pilot. An experienced pilot knows that such slippage will neither be important nor constant. In modern aircraft it oscillates around some mean point and basically has no great influence on the results of firing.

When Mishchenko learned this practicality his firing became still surer, and not only did he make progress himself, but he also managed to teach the same to the pilots of his flight.

Some of the pilots had an erroneous notion about slippage: they asserted that in producing slippage while in the process of tracking and sighting, one could obtain better results in firing. They would explain it by saying that with slippage during tracking it is easy to compare the angular speeds of the target and the fighter, which fact enables them to conduct fire in the same manner as with a fixed grid. Such statements, pointed out Mishchenko, were incorrect and incompetent.

Sr. Lt. Mishchenko's high proficiency in air gunnery is well known not only in the unit where he serves but far beyond its boundaries. At the air gunnery contest the pilot once again has demonstrated clearly his ability to destroy the target with the first volley. Fifty per cent of the fired shells found their mark!

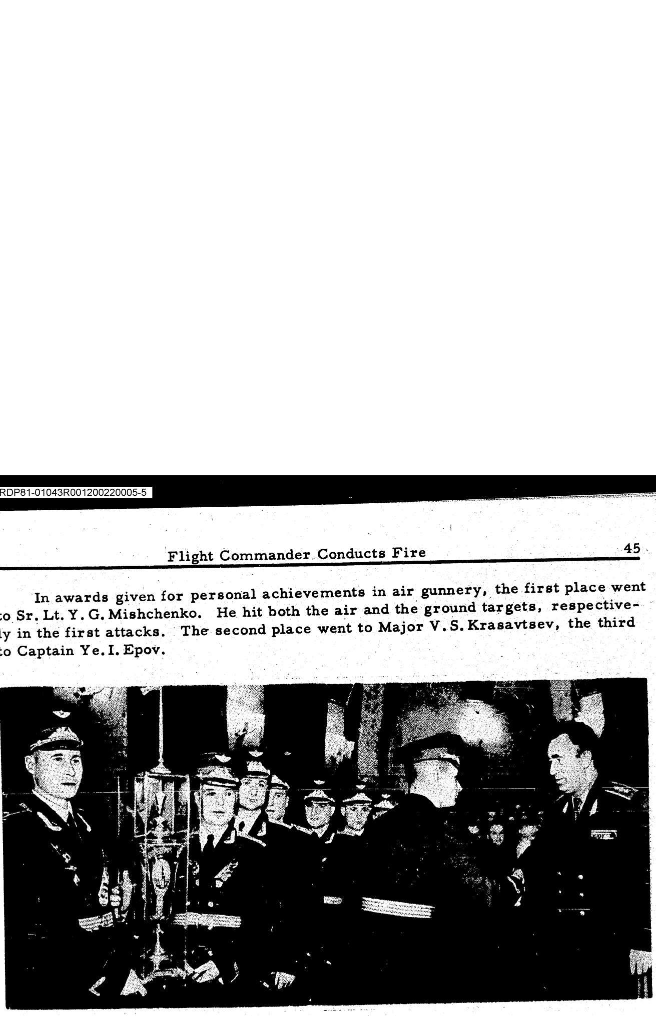
Recently a telegram arrived in the unit, congratulating Flight Commander Sr. Lt. Mishchenko upon his promotion to the rank of Military Flier Second Class.

One more stage has been reached on the way to the top of flight proficiency. And tomorrow Mishchenko will go on farther, giving of his strength, his evergy, his knowledge to his beloved work - to the honored profession of a fighter pilot, stands vigilantly on guard over the aerial borders of the mighty Soviet Union.

A ROTATING AWARD OF AIR GUNNERY CONTEST GOES TO THE WINNERS

The hard struggle in the aerial gunnery contest of 1956 between the fighter pilots is finished. Pilots conducted air battles, fired at air and ground targets. Those of the pilots who hit the target with the greatest number of shells or who gained victory in air battles were considered as having achieved the best results. Simultaneously, the observance of established rules in firing and air combat was taken strictly into account.

In awards given for personal achievements in air gunnery, the first place went to Sr. Lt. Y. G. Mishchenko. He hit both the air and the ground targets, respectively in the first attacks. The second place went to Major V. S. Krasavtsev, the third to Captain Ye. I. Epov.



Good results have been shown by pilot - interceptors. In air combat and in air target gunnery the first place went to Sr. Lt. I. Ya. Mamon. The second place went to Major P. G. Nosov who also attained high results. The third place went to Captain O. A. Kozlov.

Each new point won by a fighter pilot in individual contest gave greater chances to win to the crew to which the pilot belonged. The first place went to the crew of which Sr. Lt. Y. G. Mishchenko was a member.

The rotating award was presented to the winning crew. During the solemn ceremony the representatives from various commands warmly congratulated the pilots who had shown high proficiency in air gunnery training. At the same time prizes and valuable gifts were awarded to the winners. A motorcycle was awarded to Sr. Lt. Y. G. Mishchenko.

In the above photo, Col. -Gen. P. F. Batitskiy congratulates fighter pilot Sr. Lt. Y. G. Mishchenko on the high results achieved in air gunnery training.

Photo by V. I. Kolesnikov

EQUIPMENT AND INSTALLATIONS
AND THEIR
OPERATION AND MAINTENANCE

AIR MISSILE WEAPONS

Engineer Captain V. M. Volchkov

3. REMOTE CONTROL SYSTEMS OF MISSILE FLIGHT

By remote control we mean that branch of telemechanics which deals with the methods of control of mechanisms or processes at a distance via wires or radio with the operator present only at the control post. In general the control post may move with respect to the controlled object and may be located on land, ship or aircraft.

In the case when the jet (or rocket) engine installed in the guided missile permits relatively long-range flight, the guidance system is called upon to insure the required firing accuracy. Indeed, the control of the jet missile after launching permits correction or a considerable reduction of the errors made in aiming, which are due to technical dispersion of the missile, and of those arising as a result of the maneuver of the target, variations of the wind in altitude and direction, and the changes

of air density.

At present there are a number of different system of remote control, differing in purpose, design and also in the means of transmission of commands. The generation of command signals with the characteristics which depend on the relative distance of missile and target, and their transmission from the command post by means of transmitting devices are common to all of them. Command signals received by the receiving device located in the jet-propelled missile, are amplified and eventually actuate the servo motors of the control surfaces. The surfaces are deflected and the missile changes the flight trajectory in the required direction.

The movement of the missile is usually controlled in two mutually perpendicular planes; in the vertical by changing the pitch angle and in the horizontal plane by changing the yaw angle. In accordance with this, the system of remote control has two control channels: the vertical and the horizontal. One-channel systems are also possible; they are more compact and have smaller weight. The missile with a two-channel system is usually stabilized in flight with respect to the longitudinal axis. This is necessary in order to avoid the steering errors which can occur when the missile is flying with some angle of bank. The presence of the bank leads to a situation in which the commands, transmitted from the control point to change the flight of the missile, let us say, in vertical plane will in fact control its movements in a different plane, rotated with respect to the vertical through the angle ϕ. The stabilization is effected with the help of special gyroscopic devices. Rotation of the missile with respect to the longitudinal axis corresponds to the appearance of an electric signal taken off a potentiometer, with the potentiometer rigidly connected to the frame of the missile and the signal take-off arm mounted on the outside frame of a three-stage free gyroscope. The electric signal acts on the servo motors of the control surfaces and after a time the missile comes to a stabilized position. It is possible to do without a specialized longitudinal axis stabilization system in a system of remote control. In such a case the commands are redistributed by a special device in accordance with the rotation of the missile around the longitudinal axis.

The command signals can be transmitted to the missile from the command post via different technical means of communication. In particular, wire communication links are used for this purpose. The wire is wound on special spools mounted either on the mother aircraft or on the missile or on both of them simultaneously. To transmit the required number of commands through the least possible number of wires, both polarity and amplitude of the current pulses are used. For instance, the positive current pulse of a certain amplitude corresponds to the command "up" and the negative "down". Usually the remote control systems with a wire communication link used to control aerial missiles are made of two wires; this permits the transmission of the following commands: "up", "down" to the elevators and "left" and "right" to the rudders or ailerons. The advantages of this type of systems of remote control are: high insensitiveness to countermeasures and simplicity of operation and design. But they also have a number of disadvantages. The most serious of these are: short range of operation, limited maneuverability of the controlling aircraft and frequent disruptions of the wires with a consequent loss of control.

The most widely used guidance systems are those in which radio is used as the command link. A block-diagram of such a guidance system is given in Fig. 1. Ultra-high frequency range is usually used for transmission of control signals.

Equipment operating in the centimeter and decimeter range can also be used for this purpose. Such a system consists of a command-coding block, radio communication link, decoding and servo block and in some cases a control system. Command-coding block includes the command device which plays the role of the originator of commands, and a coding device. The encoder formulates the number and the combination of electrical pulses of definite characteristics, required for a particular command; these signals modulate the radio frequency oscillations of the transmitter.

The presence of an encoder in the remote control system is dictated by a number of circumstances. These are: the necessity to have different commands, which actuate various servo chains on the receiving side; second, because of the industrial and atmospheric interference which can cause disruption i.e. ignoring of a given command by the servo devices of the remote control system; third, because of the possibility of radio countermeasures from the enemy, who strive to interfere with the normal guidance of the missile and cause the so-called "false response" manifested by the obedience to his false commands. The encoder makes

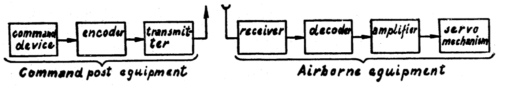


Fig. 1. Block-diagram of the remote control system.

it possible to change the character and form of the signals broadcast by the transmitting installation. A device which permits simultaneous transmission of command signals on several frequency channels can be used as an encoder.

The decoder-servo block consists of a decoder, amplifier and servo devices.

The decoder is a device which reacts only to a given combination of pulses of a very definite character. Out of all the multitude of electric pulses received by the receiving device the decoder passes only that group or that sequence of groups to which it is tuned. When the simultaneous transmission of command signals on several frequency channels is employed, a series of miniature receivers or several rf circuits are used at the output of the receiving device as a decoder. In such a system the servo components react to the control signals only upon simultaneous triggering of all the frequency channels, which reduces the possibility of the outside interference (countermeasures) with the performance of the guidance system.

The encoder and the decoder form the so-called selective device, which has the task to encode the control commands on the transmitting side and to recognize (in other words to select them) on the receiving side. There are many distinguishing characteristics by which various commands can be recognized. For this purpose there are several types of selection: qualitative, code, combination and others.

The qualitative selection is based upon the difference between the signals of one command from those of another in the polarity of the pulse, in amplitude, phase, frequency, and also by the number of pulses, their sequence and their duration.

Code selection utilizes combination pulses, differing by some characteristics with a rigidly predetermined sequence and permits a system of remote control which is free from interference not only from natural causes but also from artificially created interference.

In combination selection the servo components are actuated only when several output components of the decoder are excited simultaneously or in a rigorously predetermined sequence. This is the most effective and at the same time the most complicated type of selection.

After decoding, the signals can be amplified by vacuum tube circuits, magnetic amplifiers, pneumatic amplifiers and also high sensitivity polarized relays which connect to the executive (actuating) circuits;the field (control) coils of miniaturized motors which move the control surfaces. Electric motors, hydraulic and pneumatic actuators and electromagnets are used as servo devices.

The command device, encoder and transmitter are located at the command post. The receiver, decoder, amplifier and the servo components are located on the missile itself and comprise the so-called "on board" equipment.

As an example, let us consider the operation of one of the simplest systems, the system of remote control via a radio link. The system controls the missile in two mutually perpendicular planes. This is achieved by transmission of four commands from the command post: "right" or "left" for control in the horizontal plane and "up" or "down" for control in the vertical plane. The commands are coded by means of modulation of the transmitter's carrier frequency by audio frequency oscillations, with each command corresponding to a very definite modulation frequency. Thus, the command "right" is made to correspond to frequency f_1, "left" to frequency f_2, the command "up" to f_3, and "down" to f_4.

For missile guidance it is important to determine not only the polarity of the transmitted command signal but also its magnitude. This can be done, in particular, by adjusting the time relation between the commands "left", "right" in the horizontal control channel and "down", "up" in the vertical channel.

Let us assume that the total transmission time of the command "left", t_2, and right t_1, (we are considering the horizontal control channel) is constant and equal to $t_1 + t_2 = T$.

The distribution (allocation) of this time between the commands can be very different: from $t_1 = T$ and $t_2 = 0$ to $t_1 = 0$ and $t_2 = T$. Here the time relationship between the commands of the horizontal control channel is characterized by the so-called command coefficient, which is equal to:

$$K_{h.c.} = \frac{t_1 - t_2}{T}.$$

It is not hard to see that the value of the coefficient can change from 1 to -1. A completely analogous expression can also be derived for the vertical control channel. If the transmission time of the command "up" is τ_1, and the command "down" is τ_2, the command coefficient for the vertical channel is:

$$K_{v.c.} = \frac{\tau_1 - \tau_2}{T}.$$

The value of the command coefficient is changed by means of the command device. The main elements of the simplest command device (Fig. 2) are: special shaft 1, rotated by the electric motor 2, a control stick 3, connected mechanically to a group of contacts 4. By changing the position of the control stick the contact assembly is moved on the evolute of the shaft. The contact assembly (Fig. 3) consists of three contact plates with the contacts a and b normally closed. Contact a

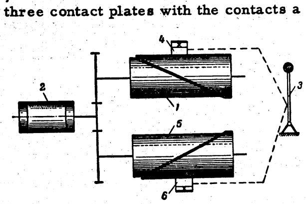


Fig. 2. Diagram of the principles of the command device.

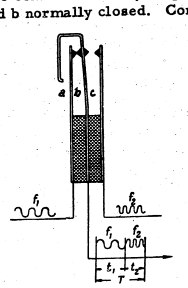


Fig. 3. Contact assembly of the command device.

is connected to the frequency generator of frequency f_1, and the contact c is connected to the frequency generator of frequency f_2. The shaft has a ridge which divides its surface in two halves of equal area (Fig. 4). The shaft is rotated with a constant angular speed, and the period of one revolution is equal T. When the contact assembly is in the middle of the shaft, the dwell time of the contacts a, b and b, c in the closed position is the same and is equal to T/2 (contacts b and c are closed when the contact assembly is sliding along the ridge of the shaft). Consequently during one of the half-periods the middle contact b (and through it the transmitter) will be connected to the generator = G, of frequency f_1, and in the next half to the generator G_2, of frequency f_2, (Fig. 5a) and the carrier frequency of the transmitter will be modulated by audio frequencies f_1, and f_2, during two equal consecutive time intervals:

$$t_1 = t_2 = \frac{T}{2} \text{ ; here } K_{h.c.} = 0 .$$

If the contact assembly is displaced to the left from the neutral position the dwell time of the contacts a and b in the closed position will be greater than that of contacts b and c and $K_{h.c.} > 0$ (Fig. 5b). The position of the contact assembly on the right half of the shaft is shown in Fig. 5b.

In this way, with the aid of the command device, the operator changes the command coefficient and controls the movement of the missile in the horizontal plane. Control in the vertical plane is effected in precisely the same manner; for this purpose the control device contains another shaft 5, and a contact assembly 6 (see Fig. 2), whose middle contact and consequently the transmitter, is connected alternately to the generator G_3, of frequency f_3 and to the generator G_4 of frequency

f_4 (Fig. 6).

From the preceding it is clear that the carrier frequency of the transmitter can be simultaneously modulated by a pair of audio frequencies ($f_1 f_3$), ($f_1 f_4$), ($f_2 f_3$), ($f_2 f_4$), which belong to different control channels.

Command signals transmitted from the control post, are received by the receiver in the guided missile, are amplified and fed into a demodulator, which in this case serves as a decoder. The demodulator consists of four resonant circuits, connected to the plate circuit of the tube = L, and tuned to the frequencies f_1, f_2, f_3, f_4 respectively, and of four half-wave rectifiers B_1, B_2, B_3, B_4 (Fig. 7). Two tank circuits are simultaneously excited; namely those tuned to the frequencies which in a given moment modulate the carrier frequency of the transmitter. Suppose these are the frequencies f_1 and f_3. An alternating e.m.f. appears in the resonant circuits F_1 and F_2. Because the principle of the control signal discrimi-

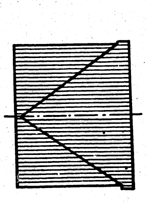


Fig. 4. The surface of the shaft of the command device.

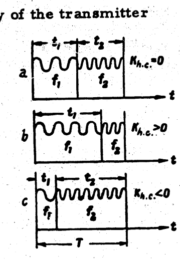


Fig. 5 Modulation graphs of the transmitter's carrier frequency.

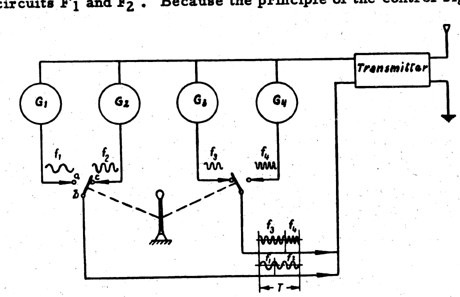


Fig. 6. Diagram of the modulator switch.

nation is the same for the horizontal, as well as for the vertical control channels, we will consider the process of control signal discrimination only in the horizontal control channel. During the time t_1 there is an alternating e.m.f. in the tuned circuit F_1. The existence of transformer coupling between this circuit and the rectifier B_1 gives rise to a voltage pulse across the resistance R_1 of duration t_1. In the next time interval t_2, the resonant circuit F_2 is excited and a voltage pulse appears across the resistance R_2 of duration t_2. The rectifiers B_1 and B_2 are connected in such a way that the voltage pulse across R_1 of duration t_1 will be negative and the one across R_2 of duration t_2 will be positive. The time relation between the pulses (command coefficient) is proportional to the magnitude of the command and is determined by the position of the control stick of the command device. Voltage pulses from the resistances R_1 and R_2 are fed in sequence to the input of the tube L_2 (Fig. 7). The control winding W_1 of the two-position polarized realy P is connected into the plate circuit of this tube. The relay P connects alternately the windings of the electromagnets E_1 and E_2 which energize the flux drop out switch S. The tube L_2 is cut off when a negative voltage is applied to its grid. In this case no current flows in the winding W_1 and its ampere turns are equal to zero. At this moment the second winding W_2 of the relay P is carrying current. The ampere-turns AW_2 in this coil insure the closing of the lower pair of contacts, the electromagnet E_2 is energized and the flux drop out switch S advances to the right.

Fig. 7. DIAGRAM SHOWING THE PRINCIPLES OF THE DECODER-SERVO BLOCK:
I - last amplification stage of the receiver; II - demodulator; III - electronic relay amplifier; IV - actuator of the flux drop out switch.

If, however, the grid of the tube L_2 is made positive, a current of such a magnitude (value) flows in the winding W_1 of the relay P, that the ampere turns AW_1 satisfy the condition:

$$AW_1 - AW_2 > AW_a$$

where AW_a is the number of ampere turns required to energize the relay P. In this case the electromagnet is energized and the flux drop out switch S is advanced to the left. Thus the time of dwell of the flux drop out switch in the position towards the right is determined by the duration of the negative pulse, and that towards the left by the duration of the positive pulse. The duration of these pulses, in turn, is determined by the command coefficient and, in the final analysis, by the position of the control stick of the command device.

Such is the principle of operation of the simplest remote control system.

As far as the passage of signals through the whole circuit of the remote-control and guidance system goes, it requires a certain (even though small) time interval, determined mainly by the time constants of the filters, lag in energizing the relay mechanisms, and also by the inertia of the control surface servos. This gives rise to a constant error, with which the control surfaces are deflected (follow) following a change in position of the control stick.

The movement of the missile is controlled through comparison of its true position with the required position at any given moment. The deviation of the missile from the prescribed trajectory represents a guidance error which is measured either by the operator or by special instruments located at the control post. Depending on the magnitude of the guidance error and the formulated program of guidance the command signals are generated. The guidance error can be measured by the operator without the use of any devices as well as with the help of radar and thermal position-check installations. In the first case the operator follows visually the trajectory of the missile and the target, and their relative position. By moving the stick of the command device the operator tries to reduce the guidance error to zero. To facilitate the tracking of the missile, tracers and powerful lights are installed in the tail section of the missile. However, such a method of control is sufficiently effective only with good visibility. Cloudiness, fog, and smoke screens limit, and in a number of cases completely preclude the application of visual control method. The flight and the position of the missile with respect to the target can also be followed on the scope of a special radar station. For this purpose a radar transponder is installed in the missile. If the target emanates thermal radiation sufficient for its detection, the missile and the target can be followed with the help of a heat detector. For this purpose a source of infrared radiation is installed in the tail section of the missile.

With the increase in distance from the missile to the command point the same angular error will correspond to linear errors of increasing magnitude. Since the power of resolution of the eye is measured in angles, wide misses are possible in the very important terminal guidance phase, i.e., close to the target, especially if the system of remote control is not combined with an active homing system.

In order to increase guidance precision a television camera is mounted in the guided missile's head. This enables the operator to follow the change of position of the missile with respect to the target and the objects surrounding it and to home the missile accurately on the target. For instance, such a television head is mounted in the American bomb "ROC". This bomb is controlled by commands in the form of pulsed radio signals which actuate the servo motors of the surfaces, controlling the position of the annular wing.

A remote control television installation includes: a television camera, television transmitter, control components and power supplies located on the guided missile, as well as a television receiver with screens, located on the mother ship. The power for the airborne equipment is furnished by the plane's powerplant.

The television equipment is considerably simpler than that used for regular telecasts, has smaller components and weight, gives high picture definition and is reliable in operation. The transition from alternate line scanning to progressive scanning with a large number of frames but smaller number of lines, the increase of the pulse width of frame and line blanking signals permits a considerable simplification of the circuit and a reduction of the number of tubes and other components of the television camera and of the transmitter.

The transmitter of command signals has several alternate (interchangeable) channels which increases its protection from countermeasures and permits a simultaneous control of several missiles. To enable the equipment to operate at high altitudes and low temperatures, the bays in which it is installed are heated.

The receiving television installation is equipped with AGC to eliminate fading. A high image contrast in daylight work is achieved by use of cathode-ray tubes with green fluorescent screens in the indicators. The interfering scattered light is weakened by special tinted filters. The first prototypes of the television equipment (in particular the equipment on the American glider bombs) worked on a carrier frequency of several hundred mc which led to antenna dimensions too large for guided missiles. This circumstance led to a change in frequency to 100 mc.

The television cameras are usually built with miniature orthicons with image transfer. With the small (miniaturized) components (50 mm in diameter, 220 mm long), these tubes make it possible to work in bad visibility, on foggy days, and in dusk, which undoubtedly extends the possibilities of combat application of remote control systems.

Fig. 8. Block diagram of the automatic remote-control system. The letter δ represents the angle of deflection of the control surface and Δ represents the guidance error or the discrepancy parameter.

High guidance accuracy, increased range of combat applicability with respect to light conditions, are undoubtedly advantages of these remote control systems. However, judging by the experience of its combat use in the Korean war, the missiles equipped with a television head for guidance were not sufficiently protected from countermeasures.

As was already mentioned earlier, the guidance errors can be determined with special equipment of the target lock-on type employed in the homing systems located at the command point. Such devices permit automation of homing of the missile on the target, and hence the elimination of the operator from this process. In some instances the aiming process is so rapid that the operator has no time to respond to the change in the homing error. Therefore the measurement of the homing error, formulation of the guidance intelligence, and its transmission to the missile are carried out automatically without the intervention of the operator in automatic systems.

Fig. 8 shows a block-diagram of the automatic guidance system. In contrast to the block-diagram of the usual non-automatic system, this diagram has a device for measuring homing error. In addition, its command link is a complicated computer installation. The guidance error is fed in the form of an electric signal (voltage) into a special computing device which automatically generates the required command intelligence, depending on the magnitude of the error and a number of other factors.

There is an alternate version of the automatic system of remote control used in the guidance of pilotless fighter-interceptors armed with guided missiles. This version, as shown in Fig. 9, requires simultaneous use of two tracking installations equipped with range finders. One of these is employed to track the target, the other to track the missile which in this case is the fighter-interceptor. Direction finding radar is most widely used in tracking installations. The data on target and fighter movements is continuously fed into the computer device which in turn continually generates command intelligence. By following these commands, the fighter aircraft is kept on a trajectory which insures its arrival in the attack position.

Fig. 9. Missile guidance system with an automatic remote control.

In particular, the American pilotless fighter-interceptor "Bomarc", designed to destroy aerial targets at altitudes where the antiaircraft missiles of the "Nike" type lose their effectiveness, is controlled with the aid of an automatic guidance system. After "Bomarc" has been launched into attack position by the remote control system, the aerial combat missile "Falcon" is launched. This missile is equipped with an active homing head.

The beam-riding system of missile control and guidance occupies a special place. Its distinguishing characteristic is that the control signals and the necessary corrections are generated by the equipment on board the missile itself. The command point, which can be located on an aircraft, on ship or on the ground, gives the trajectory with the help of a tight radar beam which the guided missile can ride. The radar transmitter, located at the command post, has a parabolic dish antenna with a rotating dipole; the longitudinal axes of the dipole and the reflector are displaced with respect to each other. As a result, the main lobe of the radiation pattern moves with an angular velocity, describing a cone in free space. The axis of the cone represents the direction of the scan axis. In this way a radio beam is formed with variable cross-section intensity, the intensity decreasing towards the center of the beam.

The command signals can be formed in different ways. One of these consists of making use of a total of four antennas, located on mutually perpendicular control surfaces. The missile's receiving antennas are connected to the main circuit of the on-board control equipment. Electromagnetic oscillations in the form of pulse signals, received by the antennas are amplified and fed to a circuit which compares the horizontal and the vertical control channels responsible for generating the command signals. After smoothing, these are fed to a relay which governs the action of the control surface servos. The equality of signals received by all four antennas signifies that the missile is moving along the scan axis aimed at the target. As soon as the missile moves off the scan axis, its receiving antennas receive signals differing in magnitude.

For instance if the missile is above the scan axis the pulse signals from the upper antenna are greater in magnitude than the pulse signals received by the lower antenna. The discriminating circuit (differential amplifier) of the vertical control channel into which both of these signal trains are fed yields signal differences. After averaging these are fed to the relay of the control surface servos responsible for control of the missile's flight in the vertical plane. The relay has two positions and the direction of its action is determined by the polarity of the formulated signal. By energizing the relay, the servo of the control surfaces of the vertical control channel is actuated. Completely analogous is the working of the horizontal control channel. As a result the control surfaces are deflected in such a way that the missile returns to the direction of flight determined by the scan axis. This tracking of the scan axis takes place during the missile's flight from the moment of launching to the moment of interception of the target.

Another method of generating of the command signals in the radio beam consists of making use of the phenomenon of amplitude modulation of the radio-pulse train received by the missile's receiving equipment. The command post, which houses the radar unit, the missile and the target can be located in straight line. In this case the missile's receiving installation receives the energy radiated by the radar transmitter, in the form of a sequence of radio pulses, with the amplitudes of these pulses being equal. In this case the pairs of commands generated by the missile equipment to control the movement of the missile in the two mutually perpendicular planes will be equal in magnitude, but opposite in sign. As a consequence the control surfaces remain in neutral position. If the missile has deviated from the scan axis the sequence of signals will be amplitude modulated. The signal characterizing the deviation of the missile from the scan axis is automatically split by the equipment on board in two parts, one of which refers to the vertical, the other to the horizontal control channels. These signals are compared with the reference signals transmitted by the command post, which leads to generation of command signals, controlling the action of the control surface servos of the horizontal and vertical control channels.

The beam riding guidance system is widely used for controlling the flight of

modern missiles. It is considered to be one of the best among the systems of remote control for air-to-air missiles. An important advantage of the system is that it is possible in principle to simultaneously control several missiles. Among the system's disadvantages should be included its comparatively small range of operation which is especially true of the missiles launched from mother planes and especially from fighter aircraft. The second major shortcoming is the possibility of enemy countermeasures with the help of special transmitter installations and also the possibility of deflection of the guiding beam by metallized tapes shot into the air. With the approach to the target the linear error in the missile's position with respect to the scan axis increases proportionally to the increase in distance, a rather undesirable characteristic. This circumstance necessitates the use of tighter beams. A tight beam, however, has a number of shortcomings. For instance the capture of the missile by the beam subsequent to launching becomes more difficult, and the probability of its exit in violent maneuvers of the target increases. The solution to the problem is found in the combined use of two radio beams; of a tight riding beam and a rather broad beam, used for capturing the missile after launching. To increase the guidance accuracy, a combined system of guidance is installed in the missile. For instance, the American beam riding air-to-air missile "Sparrow" is guided by a semi-active homing system in the terminal flight phase.

Beam riding guidance systems are also used in the initial stage of flight of pilotless aircraft and ballistic missiles.

Of all possible methods of remote control, the simplest is the line-of-sight or the three point method. The principle of this method is that the missile is maintained on the line of sight between the command post and the target. The operator who watches the missile flight continuously sees it at all times in coincidence with the target if on course. If the missile deviates from the line of sight between the command post and the target, the operator (or an automatic system) gives commands, which return it to this line again. Such a homing method can be used with the usual remote control systems as well as with the systems of control by television and also with the beam riding system. The missile's trajectory is curvilinear in this case. Overloads (stresses) occurring during the missile's flight reach their maximum in the terminal stage of flight. This leads to the possibility of the target avoiding interception by the missile. In view of this, the above method cannot be regarded as the best for destroying aerial targets moving at high speeds.

In automatic remote control and beam riding systems the methods of homing on a predicted point and the methods of free control of missile flight are widely used.

The principle of guiding to a predicted point is that the direction of the missile's flight is rigorously oriented with respect to the target and depends on its speed and direction of motion. Under ideal conditions (when the speed of the target and the direction of its motion, as well as the speed of the missile are constant) the missile flies in a straight line, which leads to insignificant overloads. Under operating conditions the target maneuvers and its speed and direction of flight change. As a result, the data fed into the computing device by the target tracking radar are transformed into commands that guide the missile to the so called momentary predicted point of interception.

The method of free control of the missile, carried out with the help of two radar units is the most flexible. One of the radar units tracks the target, the other tracks the missile. The computing device is connected to the radar and can formulate command signals, which guide the missile along a trajectory which satisfies a number of requirements (among these can be included the requirements of minimum overloads).

Other methods of guidance are possible.

The most promising are the automatic remote control systems and the beam-rider systems.

The best defense against guided missiles is the skillful maneuvering of the aerial target, creation of organized interference with the control systems and transmission of false commands. Maneuvering of the aerial target should consist of turns of the target in such a direction that the missile will undergo maximum overloads which may prevent it from carrying out orders transmitted from the command point.

MODERNIZING THE EQUIPMENT OF REPAIR DEPOTS

Engineer Major N. Ya. Frolov

Every year new equipment is added to the aircraft repair depots. Worn out and obsolete machines are replaced by modern ones which are more efficient and convenient to operate. But along with this large reserve, the repair depots are confronted with the task of modernizing the rest of the machines on hand. Along with the installation of new equipment the leading repair depots modernize the existing machinery pool. By speeding up the production processes and by mechanizing the laborious auxiliary processes they are raising the productivity and improving the working conditions of labor.

In a number of our repair depots pneumatic drills, hammers, and wrenches are widely used and automatic turrets, lathes, loaders, and jibs are in operation.

The experience of the leading depots indicates that due to the improved design of parts and the equipping of machines with new attachments the labor productivity has increased 25% and in some instances even up 1.5-3 times, while the working conditions have improved considerably.

At the depot where officer A. A. Trofimovskiy is in charge, designer G. Z. Vechkhayzer, foremen V. Ya. Kortunov and G. Ya. Brazhnikov, workmen N. A. Dudnikov, N. V. Tatarinov and others have modernized an SP 162 lathe. They designed and built a new gear box, which doubled the rate of shaft revolutions (from 500 rpm to 1000 rpm). Journal bearings were replaced with antifriction bearings which permitted working the lathe for long periods without repairs. In addition a hand brake was mounted in the gear box, which made the lathe more convenient to operate and cut down the waste of the unproductive man-hours. Moreover, the flat drive belts were replaced by V-shaped ones. All these improvements increased production 1.5-2 times.

At the same depot other machines have been remodeled. Thus, for example, according to specifications a special screw-cutting lathe centered at 850 mm was needed for repairing a jet engine. There was no such lathe at the depot. How did the innovators resolve this problem? They suggested mounting special parts under the head and tailstocks of the screw-cutting lathe which they had at the depot, and then rebuilt the top carriage of the lathe. In addition special parts were built for drive transmission from gear box to the feed unit. As a result repair of large jet engines became possible.

Much in the same way screw-cutting lathes centered at 300 mm were remodeled to accommodate the overhauling of the VK-1 jet engines. Drawings were made for modernizing the obsolete screw-cutting lathes of the "Udmurt" model, which were ear-marked for scrap metal. A new gear box with antifriction bearings was built for these lathes, and the design of the apron mechanism was altered. The modernized lathes became more convenient to operate. In a number of other lathes the shaft bearing units and carriages were rebuilt.

At present the same plant is manufacturing thread-rolling attachments for the transverse planing machines, and these have increased the production rate 3-6 times.

In the military unit when officer P. K. Grafov is in charge with comrades V. D. Gorlov, A. P. Gorokhov and others assisting they have built mechanical cutters for cutting structural iron. This made it possible to supply the workshops with properly sized material.

This military unit manufactures small parts - bolts, nuts and screws for all the Air Force repair depots. In mass-producing the parts they make efficient use of automatic turret lathes, cold-upsetting machines and thread generating machines. The cost of parts is cut by 1/2 - 2/3 as compared with manufacturing them on the spot at every depot.

When gearing up for mass production of some parts this military unit encountered difficulties - special machinery was not available. Here is where the innovators of the unit helped out. For instance, special small machines were needed for facing and counter boring of nuts. Comrades Gorlov and Gorokhov rebuilt a small obsolete machine which at one time was used for valve buffing, they made a special carriage which made it possible to face and counterbore the nuts simultaneously. Innovators V. F. Stepochkin, A. A. Leonov and A. I. Yegunov have developed a special machine for this purpose.

The operating principle of this machine is as follows: by shifting the hand lever of the headstock to the right, the shaft is engaged; the nut is screwed onto the chuck inserted into the shaft. When the hand lever of the tailstock is shifted away from the operator the face of the nut is tooled, while by shifting the hand lever to the left the inner edge is taken off. After taking off the edge the spring returns the shaft of the tailstock into the initial position. When the hand lever of the tailstock is shifted toward the operator and to the left, the outside edge is taken off. Shifting the hand lever of the headstock to the left throws the shaft into reverse and the nut is taken off the chuck with a wrench. The delivery head of the tailstock slide block is limited by braces.

This same team of innovators has built a specially designed cutting tool for simultaneous facing and counterboring of nuts and also cartridge fuses for nut threading drill presses.

For tooling the bolts (for VK-1 engines) which have a ball-shaped cap and a complex pattern of cuts, the innovators modernized the machines of obsolete design - thread milling and turret lathe. They built for them a number of additional attachments for simultaneous fixing of a large quantity of bolts and tools. In this way machines of obsolete design are used effectively for bolt tooling.

As a safety measure the grinders and the guillotine are equipped with photoelectric cells.

M. K. Tirik, head mechanic of comrade U. I. Shvedchikov's military unit, together with a group of machinists and skilled workmen have built and installed a device for pneumatic removal of shavings from the carpenter shop, and also mechanized the coal delivery to the boiler room.

In comrade M. S. Kolenko's military unit, the innovators have built a duplicate milling machine jig for milling the generator hoods. This facilitated the work of the operators and sharply increased the productivity of the operation.

There are many such instances of live creative initiative of the innovators. Repair depots where machine modernization, operation and mechanization of work is well organized, as a rule, fulfill and over-fulfill their production norms.

DILIGENCE, SKILL, INITIATIVE

Senior Lieutenant M. F. Rebrov, Engineer Service

The wan light of early morning shines weakly on the airfield installations powdered with snow. A small neat hut glistens white at the very edge of the field to the side of the apron. This is the workshop of the group handling regulations adjustment and repair of electrical and instrument equipment. From early in the morning a business-like bustling activity begins here.

The hut looks attractive and unusual on the inside. Everything in it reminds one of a small science laboratory. Neatness and order are all about. Tables, stands, and mountings are arranged along the walls for checking various instruments and assemblies. Over them hang neatly drawn electrical diagrams, placards, rules for use of individual instruments and mountings. Instruments and register plates are carefully kept in special compartments in the table drawers. Every screwdriver, every wrench, even the smallest, has its own place and its own marking. Instruments are assigned not only to electrical or tool specialists, but also to each work bench.

Aircraft instruments are neatly laid out in a spacious closet. On the shelves are plates: "instruments for installation on an aircraft", "instruments for checking", "barospeedgraphs", "mountings." Expendable materials are kept separate - safety wire, electric wires, "durites", spare parts, etc.

Senior Technical Lieutenant A. Ye. Gusel'nikov

The regulations work group is headed by Senior Technical Lieutenant A. Ye. Gusel'nikov - a modest and industrious officer, who knows his aviation equipment. This man, the originator of many mountings and stands, has five author's certificates to his credit. Gusel'nikov completed aviation mechanic school for special services in 1942. He worked as mechanic on electrical lighting network in training programs for flight commanders. And now for over 13 years he has been with a regiment in which, during the war years, he fought gloriously from Smolensk to Koenigsberg. Although he had become a good specialist in instrument and electrical equipment, Gusel'nikov did not abandon his studies and in 1946 completed a correspondence course for radio mechanics. "An excellent man, a skilled specialist, and a disciplined officer" is what they say about him in the regiment. In 1954 he was appointed chief of the regulations work group. It was here actually that the communist Gusel'nikov's organizational talents came to the fore.

As in every important undertaking the formation of the regulations work group greatly interested the soldiers. Difficulties were encountered at first: there were no quarters, there was insufficient equipment, experience in working with the new system was lacking. Everything was set up with their own hands. They worked day and night, at the same time carrying out regulations work on planes.

Regulations work is the most important integral part of the technical operation of air force equipment, and the special equipment of a modern jet plane is a large and complicated set-up. A thorough checkup of it is no simple matter. Such a checkup requires not only the detection of external damage but also the knowledge of how the special assemblies behave under the various operating and load conditions that may arise during a flight. During their free time they often had to pour over books, and study descriptions of factory-made testing installations. The main difficulty, however, lay in the fact that there was not enough testing apparatus. Much effort had to be exerted to arouse the creative initiative of the subordinates, and to imbue them with the aspiration to perfect methods of testing and repairing instruments and assemblies.

And now the small team from the group, by searching persistently, was making simple and convenient devices which facilitated the testing of instrument and electrical equipment. Various plans would arise, the first sketches and drawings would be made, and these gradually took the shape of neat diagrams.

During the first few months, the efficiency experts of the group developed devices which facilitated the testing of aircraft headlights, "thermo-alarm" devices, presses for testing manometric instruments, an oven for drying silica gel and others. Many units were developed from the ideas and drawings of the group chief. Thus Gusel'nikov designed a gyro horizon trainer - an original unit for testing the booster pumps in the aircraft fuel system, a device for bleeding the dynamic and static conduits of the air pressure intake, mountings for control of pressure signal apparatus and trimming tab control motors. All this enabled them to make a significant reduction in the time needed for testing and to raise the quality of the regulations work.

The question of the technical know-how of the electrical mechanics and instrument workers became acute. The characteristics of technical proficiency are neatness, exactness, and good organization of work; and many soldiers were lacking in such qualities. Not infrequently it would happen that while working on a plane, some soldiers would even ignore the rules laid down in the instructions. Once Private M. K. Verbitskiy was replacing an oxygen apparatus. He set about his work with dirty, greasy hands, thus violating the basic safety rules. In an attempt to complete the task as quickly as possible, he failed to plug the stub pipes of the oxygen apparatus. Verbitskiy is a capable mechanic, but he lacked sufficient organization and neatness in his work. Gusel'nikov reprimanded him, and after work he assembled the entire personnel of the group and, summing up the events of the day, explained to the soldiers what such a violation of instructions could lead to. Owing to the high chemical activity of compressed oxygen, even if an insignificant amount of oil and dirt got into any assembly of the oxygen equipment, an explosion or a fire could result. Now such incidents have been eliminated from the work of the group, and all the specialists have become convinced, by many examples, of the fact that equipment lasts considerably longer if it is handled competently and with love.

The group chief conducted several training exercises with his subordinates right on a plane, showing them how to carry out separate operations connected with dismantling, mounting, and testing of special equipment by the use of testing units and various devices. He paid a great deal of attention to the correct use of instruments, testing apparatus and to the meteculous observance of the technology of regulations testing and repair.

In 1955, Gusel'nikov as the best efficiency expert was sent to an exhibition of the work of efficiency experts and inventors. Among the large number of various devices and test mountings, there were also on exhibit many stands for testing electrical equipment. Studying the diagrams of the stands carefully, he pondered more and more over the problem of how to make the stands less bulky and at the same time how to use them for testing a considerably larger number of assemblies. And such a stand was made. The efficiency experts of the group expended a great deal of work on it, changing and perfecting the design. The difficult days of searching were over. The stand is now finished and makes it possible to check all types of relays, gauge strainers, starting coils, a starting panel, a starter, a carbon voltage regulator, an automatic starting-time device, volt-ampere meters, and also to recharge batteries. This compact and convenient device has been highly rated by aviation specialists and is widely used in other units of the air group.

The work in Gusel'nikov's element is conducted in such a way so as not to overlook a single defect or even the most insignificant malfunction. In each individual case, a careful analysis is made of the failures of the special equipment, the causes giving rise to them are brought to light, and effective methods for detecting and eliminating the malfunctions are looked for. The chief of the group records the most typical and difficult cases in his log.

An incident that occurred with a gyromagnetic compass is interesting, for example. Once, after some flights, pilot Captain V. T. Matrosov complained about the working of the instrument in the air. The turn indicator needle on the distant gyromagnetic compass kept oscillating all the time and moving unevenly during turns of the plane. A test directly on the plane yielded no results. Various suggestions were given, an attempt was made to replace the amplifier, but all in vain.

The work day was drawing to a close, the technicians put covers on the planes, and the reason for the strange behavior of the instrument had not even been found. Returning to the group, Gusel'nikov ordered everything to be made ready for a bench test. All the parts of the assembly were placed in turn, but the result was the same. All were thinking hard, trying to get at the reason for the abnormal functioning of the instrument.

"Let's switch it on once more," said the officer.

And at this point Gusel'nikov directed his attention to the following seemingly unessential detail - at the moment that the PAG-1F transformer was turned on, something would make a strange howling sound. The transformer was replaced, and the instrument began to function properly. The transformer was taken apart. It turned out that at the moment it was switched on, the magnetic system in it would keep unwinding.

A detailed analysis in such cases makes it possible not only to train the soldiers to check the aircraft instruments and assemblies carefully and to foster in them a feeling of responsibility for the care of aviation equipment, but also enables the regimental engineer to plan correctly an assignment for preventive inspection day

of matériel. The group specialists bring to light various defects in the process of the functioning of the assemblies on the plane or on the stand. The typical symptoms of these defects are recorded in the group in a special log, where the outward symptom of the failure and its cause are pointed out. For example, the voltage generator grows with an increase in speed of rotation up to more than 30 volts - a break in the circuit of the operating coil of the carbon voltage regulator, or - sparking under the brushes of the electric motors - brushes worn out or broken down, etc.

Officer Gusel'nikov strives persistently to improve the quality of the regulations work and to cut down on the time needed to carry it out. Thus, formerly, the aircraft's instruments and assemblies undergoing inspection in the group, would be removed from the plane and taken for a checkup in turn. But experience has shown that this entails inconveniences. Now they are all removed from the plane at the same time, and transferred to the group in a special box. At first glance it seems that the innovation is actually not so great, but this way much less time is spent on the work. Another difficulty lay in the fact that when a plane's generator was checked or when it was removed for replacement, much time was spent on dismantling the plane. A way out of this situation was sought for a long time, and it was found: a special wrench was made, "a sly wrench" as it is jokingly called, with which it is possible to remove the generator without dismantling the machine. Examples of this kind are not rare.

Many men were at first frightened, for example, by the structural complexity of the gyro horizon. Even if they found some insignificant defect, they would summon a plant representative. Frequently it would happen that the representative was held up and there was no properly working instrument on hand for replacement. An incident is brought to mind, which put an end to this situation. Once a gyro horizon was brought to the group with the complaint that the gyro motor would accelerate sluggishly when it was turned on, and that during a flight an obstruction of the spherical scale was observed. A test of the instrument on a special mounting gave no results, and there was no new one on hand.

"Maybe it would be better, after all, not to wait for the plant representative but to try to do it ourselves," thought the officer.

The instrument was taken apart. It turned out that one of the correction motors was not working, because the brushes in the slip ring assembly had become slightly burned. When the carbon and fouling had been cleaned off the brushes and the gyro horizon was tested again according to all parameters, they were within the specified norms.

The group chief is responsible not only for carrying out the regulations work promptly and well but also for the technical training of the personnel, for their education. The group chief is a single-commander - a leader and indoctrinator of the troops.

In order to weld the element together into a single combat unit, the commander must always take many factors into consideration: the character, habits, tendencies, and professions of his subordinates. Only by knowing thoroughly the positive qualities and the shortcomings of each man, will he be able to train skillful and disciplined soldiers.

Officer Gusel'nikov spends a great deal of time in the barracks where the personnel of the group are quartered, systematically sees to maintenance of order in their quarters, and requires that his subordinates always be neat and smart, that they have the outward appearance and bearing of real soldiers. In an effort to become better acquainted with his subordinates, he often questions them in simple free and easy conversation, about their service, their difficulties in training, and about their relatives and friends; and he tells them about himself. Such contact brings people close and helps them overcome difficulties and achieve success in work.

And the element has had considerable success. The quality of their work with aviation equipment has risen, the ranks of outstanding men have grown. Sergeant S. M. Badanin and Private N. N. Morozov have been awarded the chest insignia of "Outstanding Airman." In a unit order of the day, Privates M. M. Lazurenko, M. K. Verbitskiy, and others were proclaimed outstanding in political and combat training.

Much effort and energy was expended and many joys and failures were experienced, before the group team assumed a foremost position. Let us take Private Morozov, for example. During his first days of army service, the soldier could not keep up with his work: it was difficult for him to become familiar with the matériel, especially electrical circuits, he had no practical work habits, and he felt no responsibility for carrying out an assigned task. The group chief had to exert a great deal of effort to help the young soldier. He would show Morozov the correct procedure for conducting separate operations in dismantling and installing equipment, how to check it with a testing apparatus, how to eliminate defects which had been detected and then he would observe how the latter did all this by himself. Time passed. From day to day the soldier became better and better acquainted with the "secrets" of technical operation and maintenance . He would study the equipment carefully and was mastering his special field. Persistent work brought success.

Once during a preventive test on a MiG-type trainer, it was discovered that the automatic protective grid in the circuit of the trimming tag control motors was developing malfunction. The men started to look for the cause.

"It's a short circuit," decided Morozov. "But where?"

The difficulty in determining the location of the defect lay in the fact that the automatic protective grid included two trimming tab control motors and two electric turn indicators. After mentally setting up an electric circuit, and after consulting with the group chief, he decided that a positive wire was shorting. Upon checking the motors, he became convinced that everything there was in good working order. Consequently, the defect had to be looked for in the circuit of the turn indicators which were switched in, in parallel fashion, in such way that one wire led to the automatic protective grid. Working with a needle, Morozov checked in turn, all the sections of the circuit and between the first and second compartments he discovered that a positive wire was making contact with a stringer.

An individual approach to each soldier of one's element occupies an important position among the various forms of training work. But in this respect as well, Gusel'nikov does not act in a stereotyped manner. In one case he encourages a soldier who has encountered difficulties in his training or in his work and tries to build up the latter's confidence in his own powers; and in another instance, he becomes even more exacting, requires perseverance and persistency, makes the soldier study and work to his full capacity.

Aviation specialists understand the role the regulations play in the general complex of the technical and flying operations of the complicated electrical and in-

strument equipment of an aircraft. They also understand that the most important and basic way to achieve mastery is through painstaking daily training, and through the search for new more efficient maintenance methods.

Sergeant S. M. Badanin carrying out regulations work on a dismantled aircraft.

While training his subordinates, the group chief strives to create conditions approximating those of combat. Thus, the element would not infrequently carry out regulations work at night under complex conditions. But even in these instances all the work would be carried out efficiently and on time. More experienced comrades too would help him.

Much credit for the formation of the group goes to Major M. S. Kurguzov, Technical Service, the unit engineer for special equipment. An experienced worker, a skillful leader, and a tactful comrade, he helped Gusel'nikov overcome the difficulties the latter had encountered, exerted a great deal of effort and energy to bring about efficient work on the part of the regulations work group.

A feeling of keen responsibility towards one's assigned task, high standards imposed on oneself and on one's subordinates - that is what assured Gusel'nikov's success.

What is the net result of all this work? An inspector's checkup has shown that the group's equipment is in excellent condition. Gusel'nikov's group has been placed in competition with the best training bases and regulations work groups.

... The express train was carrying Gusel'nikov to a far-off city. Before him was a year of intensive training at an advance training school for officers. But the group chief was calm: he had placed the management of the group in reliable hands. The officer has faith in his subordinates, knows that the soldiers have skillful hands and they do everything conscientiously. His deputy is Sergeant S. M. Badanin, an efficiency expert well known in the group, outstanding in political and combat training who commands the respect of his comrades. Such a man will justify the trust.

FROM THE HISTORY OF SOVIET AVIATION

SOVIET PILOTS IN THE BATTLE OF ROSTOV IN THE FALL OF 1941

Major V. N. Myagkov, Candidate in Military Science

The combat operations of the Soviet troops in the Rostov-na-Donu area in the fall of 1941 constituted one of the main events during the first months of the Great Patriotic War of the Soviet Union against Fascist Germany. In the course of these battles the German Fascist invaders suffered great losses in manpower and combat matériel, a fact which exerted considerable influence upon a number of subsequent operations. The Soviet Army succeeded, under difficult conditions, in stopping the advance of the Fascist troops on the southern wing of the Soviet-German front, in inflicting heavy losses upon them and then in throwing them back beyond Rostov. Soviet air forces also took active part in these battles, side by side with other branches of the Soviet Army.

As is well-known, by October 1941 the Hitlerite invaders had succeeded in reaching the line running through Artemovsk, Gorlovka, Novo-Pavlovka, D'yakovo, Lysogorka, the Tuzlov River, General'skoye and Chaltyr' (see the map). The enemy's 1st Tank Army which had been reinforced by units of his 4th Air Force and which had been advancing along the coastline of the Sea of Azov, was seeking at all costs to seize Rostov-na-Donu, a large administrative, industrial and cultural center and an important communications hub, connecting the central areas of the country with the Caucasus.

The Fascist Air Force based mainly on the airfields of Stalino, Taganrog and Mariupol' (now Zhdanov) consisted of up to 100 fighters (Me-109 and Me-110), 80 bombers (Ju-87, Ju-88), and 20 reconnaissance planes of various types.[1]

Soviet troops, made up of the Southern Front and of the 56th Army, were offering resistance on the southern wing of the Soviet-German front. In number of planes, the air force of the Southern Front and of the 56th Army was not inferior to that of the enemy.[2] Yet, as also on other sectors of the front, up to 80% of its planes were of obsolete design. The pool of new bombers and ground attack planes was too small. Thus, for instance, there were in all 17 ground attack planes in the 4th and 5th Reserve Air Groups. Besides in the air units there were many planes in disrepair. Thus, some air divisions had only 10-15 serviceable aircraft each.

Repair of matériel and supply of the large air units became extremely difficult

1. Ministry of Defense archives, stock 319, inventory 391557, file 1, sheet 12
2. Ministry of Defense archives, stock 319, inventory 391557, file 1, sheet 13

because of repeated shifting of bases connected with the forced withdrawal of Soviet troops to the east. All this made the struggle against a technically well equipped enemy more difficult.

Speaking of the conditions of combat activity of Soviet aviation which took part in the battles of Rostov, one must not overlook the circumstance that the airfields on which the air units were based were located very far from each other and this hampered the organizing of co-operation between air units and ground forces. There was considerable trouble too in the tactical control of air units and groups. But there were air units were distributed evenly among the combined arms groups. But there were few aircraft under direct control of the commander of the front, a situation which limited the possibilities for concentrating its efforts in the most important sectors.

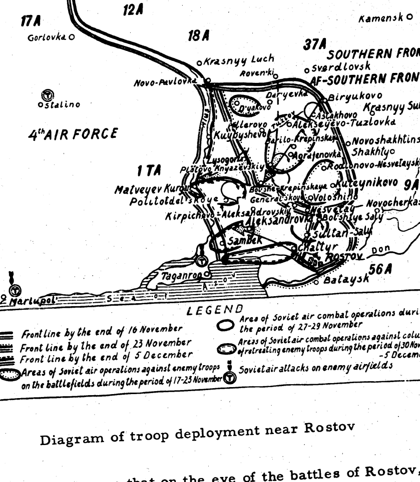


Diagram of troop deployment near Rostov

All these facts prove that on the eve of the battles of Rostov, conditions had shaped up extremely unfavorable for Soviet air forces.

The enemy, superior in manpower, artillery, and particularly in tanks, turned to the offensive on 5 November 1941. The troops got the assignment first to fight

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their way into the Shakhty area and then to seize Rostov, with a thrust from the north and north-east. Fierce battles flared up in the northern regions of the Rostov oblast. Our pilots also operated very energetically and vigorously in these battles. Enemy tanks on the battlefield were the main objective of our air operations, as also in other sectors of the front.

The 4th Ground Attack Air Regiment of the Order of Lenin carried on very intensive combat operations under the command of Air Force Major General S. G. Get'man, now Hero of the Soviet Union. Ground attack pilots of this regiment kept strafing accurately enemy troops and matériel with bombs, rocket shells, machine gun and cannon fire. Nikolay Sinyakov, pilot and Komsomol member particularly distinguished himself here. He would make two or three sorties a day to attack the German Fascist troops. During one mission the courageous Komsomol member bravely engaged an enemy fighter plane in aerial combat and shot it down. On 30 October 1941, Nikolay Sinyakov repeated the immortal exploit of Captain Gastello by crashing his burning plane into a column of enemy motor vehicles with ammunition.

Besides using bombers and ground attack planes, the Soviet command started bringing in fighter air units equipped with I-15, I-15-2, I-15-3, and I-16 planes for operations over the battlefield.

Thus a group of Soviet fighter planes made up of eight I-16 aircraft of the 88th Fighter Air Regiment was given the assignment to strike an assault blow at the Hitlerites who were advancing in the region of Bol'she-Krepinskaya. While carrying out this assignment the Soviet pilots spotted a column of approximately 20 tanks which had broken through into the rear of our ground units. There was also a group of Soviet tanks not far from the enemy column. Wishing to help their own tankmen, the Soviet pilots decided to lead them to the target. They came down over the Soviet tank column and then, with a zoom followed by a dive, they pointed out the target by first attacking the enemy tanks themselves. Fighter planes in a dive attack struck at them with rockets and cannon fire. Following the fighter attack on the enemy tanks came the attack by our tankmen. Several enemy tanks were destroyed. The attack of the enemy tank column had been halted.[3]

Fascist air units supporting the advance of the 1st Tank Army kept striking at our troops on the battlefield as well as in the immediate rear. In groups of 30-40 planes, enemy Ju-87 and Ju-88 dive bombers covered by fighter aircraft, frequently bombed our troops. One of the primary tasks of the Soviet fighter units was to beat off these air raids. Our fighter-pilots made 5-6 sorties a day.

As a rule each air battle took place with numerical superiority on the side of the enemy. Nevertheless, the Soviet pilots with their sudden decisive attacks kept inflicting losses upon the enemy. As a rule they carried out the attacks in a direction away from the sun or from behind clouds, in an attempt to rout the enemy with the first blow. As was shown by the experience of that time, repeated attacks seldom succeeded in downing the enemy.

In the course of a defensive engagement a rapidly changing situation required a great expenditure of manpower and resources to carry out air reconnaissance. As

3. Ministry of Defense archives, stock 319, inventory 391558, file 1, sheet 72.

a rule, this reconnaissance was organized, with consideration being given to one's own manpower and resources as well as to conditions which would ensure the suddenness of its execution. Visual air reconnaissance was usually carried out by a group of fighter planes. But if it was necessary to obtain air photos of the most important objectives an SB reconnaissance bomber was detailed with strong fighter cover. Air reconnaissance sorties were often accompanied by air battles.

For instance on 8 November at 13:30 hrs a flight formation, made up of three I-16 planes and one I-153 was conducting a reconnaissance in the region Agrafenovka, Bol'she-Krepinskaya, and Nesvetay. Eight Me-109's attacked the flight formation. Flight commander Jr. Lt. Dvorskiy, the pilots, Lt. Bogrov, Jr. Lt. Prikhodchenko and Sgt. Kuznetsov accepted combat in spite of the numerical superiority of the enemy. Forming a circle our fighter planes successfully repulsed the enemy attacks. The plane of the flight commander was damaged in this air battle. In a burning aircraft Dvorskiy landed on territory, occupied by the enemy. Sgt. Kuznetsov chose a suitable landing place close to the spot where the commander had landed, made a successful landing, took him aboard and thus saved his life.[4]

A. I. Pokryshkin who subsequently became a Hero of the Soviet Union three times, proved to be an able air reconnaissance pilot in the battles of Rostov. In a MiG-3 plane he carried out air reconnaissance assignments excellently, under the most complex weather conditions, and supplied his superiors with valuable information. For skillful execution of responsible assignments, A. I. Pokryshkin was awarded the Order of Lenin.

The offensive of the enemy 1st Tank Army was halted on 9 November by the joint efforts of the ground troops and the air forces, on the line running through Roven'ki, Biryukovo, and Novoshakhtinsk. After this, the Soviet troops began to prepare for a counteroffensive. The main task in the approaching counteroffensive was assigned to the 37th Army, which had been newly activated as part of the Southern Front. From the area north-east of Shakhty units of this army were to attack Bol'she-Krepinskaya on the flank of the 1st Tank Army, in order, through joint action with the 9th and the 56th Armies, to destroy the main enemy tank grouping, which was operating on the southern wing of the Soviet-German front.

The main forces of the Southern Front air force were detailed to support the 37th Army. By special order of the Military Council of the Front, a series of air units from other armies was attached to the 37th Army. Moreover, the latter was to be supported by the 5th Reserve Air Group, the 22nd, 66th and 76th Air Divisions. As a result, 153 serviceable planes, making up the greater part of the entire air force of the Southern Front[5], were successfully concentrated in the direction of main attack.

The AF Hq Southern Front worked out a plan of combat application of aircraft, according to which the air forces were to solve the following problems: win supremacy in the air by attacking airfields and destroying enemy planes in air battles; support the advancing troops of the main attack forces of the front, by destroying enemy tanks, artillery, and manpower on the battlefield and in the immediate rear; carry

4. Ministry of Defense archives, stock 319, inventory 391558, file 1, sheet 74
5. Ministry of Defense archives, stock 319, inventory 391557, file 1, sheet 13

on interrupted air reconnaissance and battlefield observation.

Before the beginning of the offensive, it was planned to use the full strength of the Air Force of the Southern Front, to strike a blow at the enemy combat formations in the zone of advance of the 37th Army. The air force combat action plan was drawn up for the entire operation, for each of its stages.

In spite of the limited time available for the preparation of a counteroffensive (from 10 through 16 November) the air units of the front carried out a considerable amount of work in organizing coordinated action with ground troops, in repairing matériel, and in setting up on the airfields reserve supplies (fuel, aerial bombs) necessary for carrying out active combat operations. To insure close coordinated action with ground troops and more reliable control over the air groups, their commanders organized auxiliary command posts in the immediate vicinity of the main line of defense.

All measures connected with preparation for the counteroffensive were given close attention by political organs and party organizations of air units and groups. By means of their organizational and educational work, they assisted the command in preparing for the operation as well as in mobilizing personnel to carry out assignments.

On the eve of the offensive brief meetings were held in the political sections of the air groups, at which the political workers of units and elements received specific instructions for organizing party political security of combat activities. The units and groups held open Party meetings at which measures were discussed aimed at attaining the best fulfillment of tasks assigned by the commanders to the flight and technical personnel. By their personal example, the Communists and Komsomol members, fired the enthusiasm of vast masses of pilots. The high morale and political zeal with which the Soviet pilots greeted the order to turn to the offensive was an important prerequisite of their successful actions in battles.

The offensive of the Soviet troops began on 17 November 1941. After half an hour of artillery preparation, units of the 37th Army attacked the enemy at 09:00 hours. The Hitlerites had not expected the advance of our troops. Having broken the resistance of their forward elements, the Soviet troops began to pursue the hastily retreating enemy. On the first day of the offensive our troops advanced 16-18 kilometers. But, owing to unfavorable weather, utilization of the air force was limited during the first three days of the offensive. Only individual aircrews, best prepared for flight under difficult weather conditions, were called upon to carry out combat missions. In the main these crews carried out air reconnaissance assignments. Some shortcomings in the combat operations of the ground troops as well as the lack of necessary air support could not but have a telling effect on the results of the offensive. The enemy succeeded in stopping the advance of the main striking force of the front on the line running through Dar'yevka, Astakhovo, Boldyrevka, and Rodionovo-Nesvetayskoye.

The Fascist Command, deciding that the Soviet offensive had been definitely broken, dispatched the main forces of the 1st Tank Army to seize Rostov. After fierce battles, the enemy occupied the city, yet he could not develop his advance against Northern Caucasus, because the main striking force of the Southern Front of Soviet troops threatened his weakly protected northern flank.

On 20 November, troops of the 37th Army renewed their offensive, this time

with active air support. Having broken through the enemy defense on 23 November, they reached the Tuzlov River and seized the important strongpoint of its defense - the Bol'she Krepinskaya stanitsa.

From 20 to 23 November, the air units of the Southern Front took advantage of an improvement in the weather to give considerable support to our advancing troops. During these days they made 1609 combat sorties inflicting considerable losses on the enemy in manpower and equipment.[6] Their attacks were based mainly on air reconnaissance data, but sometimes they also acted according to requests made by ground troops. While solving these problems Soviet pilots fought also against enemy antiaircraft weapons, for which purpose special aircraft were detailed from the groups.

Such was the case on 20 November when an attack was made on a concentration of enemy troops in the region of the state farm "Ovoshchnoy". Nine I-15-2 fighter planes and three I-16's loaded with demolition and fragmentation bombs and covered by six LaGG-3 fighter planes set off on this mission. Several crews from the air group were detailed to neutralize the fire of enemy antiaircraft artillery. Dive bombing from an altitude of 500 m our pilots destroyed three tanks, six motor vehicles and one antiaircraft gun. The group suffered no casualties.[7]

The fighter pilots who fought most effectively against the German Fascist air force were those who were able to attack the enemy suddenly and energetically, opening fire when at close range. In such cases they often succeeded in gaining victory without any casualties even with a very unfavorable correlation of forces.

A group of fighter planes headed by Sr. Lt. Luk'yanov was to strike a blow on a concentration of enemy motor vehicles in the Alekseyevo-Tuzlovka area. While crossing the front line Soviet pilots noticed eight Ju-87's trying to bomb our troops. At an altitude of 1200 m, our fighters resolutely attacked the enemy. After the first attack they upset the combat formation of the enemy bombers and after shooting down two planes, they forced the remainder of them to drop the bomb load on their own troops.

The not always correct utilization of new planes that arrived as replacements (Yak-1, MiG-3 and LaGG-3) must be considered as an essential shortcoming in the combat employment of fighter aircraft of that time. Many pilots attempted to conduct air combat in them, by applying horizontal maneuver alone, though the advantages of the new equipment permitted a large scale application of vertical plane maneuver.

Supporting the advancing troops, the front-line bombardment aircraft kept striking blows at the enemy's main strong-points and resistance centers. How effective the bomber assistance to the ground troops was may be seen from the instance of the seizure by our troops of D'yakovo, a strongly fortified enemy strong point.

Our ground troops fought stubbornly for more than 24 hours against the Fascist troops defending D'yakovo. It was decided to utilize bomber aircraft to neutralize the fire system. On 23 November, nine SU-2 planes delivered an attack on the

6. Ministry of Defense archives, stock 319, inventory 391558, file 1, sheet 94
7. ibid., sheet 89

enemy troops in D'yakovo. Immediately after the bomber attack, units of the 136th Rifle Division attacked the enemy and seized this large strong point of his defense.

Further advance of the Soviet attacking units presented a threat of encirclement of the main forces of the 1st Tank Army of the enemy. To avoid encirclement the Fascist Command was forced to shift hastily part of its forces from Rostov to the breakthrough area. This, however, not only weakened the enemy's defense of Rostov, but it also created favorable conditions for Soviet Army units to seize the city. On 27 November the troops of the Southern Front, after having regrouped previously, opened an offensive against Rostov from the northeast and from the south. The main efforts of the Soviet air forces were directed at supporting the troops of the 37th and 9th Armies, advancing on the city from the north. Bombers and ground assault planes kept striking blows at enemy combat formations in the area of Nesvetay, Sultan-Saly, and Bol'shiye Saly.

During these decisive days of the battles for Rostov, combat activity of the enemy's air force increased greatly. He shifted air units to Rostov from other sectors of the front. According to reconnaissance data, 110 enemy planes were massed on the airfields of Taganrog and Mariupol' alone. The Soviet air forces delivered a series of bombing and strafing attacks on these airfields.

It was the ground attack and fighter planes that carried on operations against airfields most successfully. Thus, for example, a flight of Il-2's, headed by Capt. I. P. Mos'panov destroyed eight planes[8] on the Taganrog airfield during one sortie alone. More than once, Capt. Mos'panov successfully led groups of ground assault planes to carry out the most responsible combat missions. He died the death of the brave in June 1942 in the region of the Kagal'nitskaya stanitsa of the Rostov oblast'. He was posthumously awarded the title of Hero of the Soviet Union.

The pilots of the 298th Fighter Air Regiment also were no less successful in destroying enemy matériel on airfields.

Soviet air attacks on enemy airfields forced him to disperse his materiel and to shift the bases of his air groups further to the rear; this could not but result in effecting an improvement of our Air Force's prospects in the air.

On 29 November, Soviet troops liberated Rostov. The routed units of the 1st Tank Army of General Kleist began to withdraw to the west. The Soviet air force, assisting the ground troops, kept bombing the columns of the retreating Fascist troops, particularly at the crossings over the Mius River.

Nevertheless our troops did not succeed in disorganizing the enemy's retreat completely. He consolidated his position at the Mius River and at the approaches to Taganrog. From 5 December on the front line became stabilized.

In the counteroffensive at Rostov, Soviet troops and air units inflicted a serious defeat on the enemy's 1st Tank Army. During the counteroffensive, the Southern Front Air Force made about 4000 sorties[9] in spite of complex weather conditions. The battles of Rostov were the first school in combat actions in an offensive operation for many Soviet pilots who later became able air fighters, and commanders of elements, units and groups.

8. Ministry of Defense archives, stock 319, inventory 391558, file 1, sheet 99
9. Ministry of Defense archives, stock 319, inventory 391557, file 1, sheet 13

SOMETHING NEW IN THE N. Ye. ZHUKOVSKIY MUSEUM

In 1956, thousands of people visited the N. Ye. Zhukovskiy museum which was founded by decision of the Council of Ministers of the USSR at 17 Radio Street, Moscow, where N. Ye. Zhukovskiy had worked from 1915 to 1920.

A great amount of very valuable materials connected with the life and activity of N. Ye. Zhukovskiy has been concentrated there. The museum has acquired his private library (5000 volumes) as well as part of the A. M. Kovan'ko library. Manuscripts of the works of Nikolay Yegorovich Zhukovskiy, the first works of TsAGI (the Central Aerohydrodynamic Institute) and many interesting documents of various kinds, have been collected.

Restored and on exhibit is the original flat wind tunnel designed by A. N. Tupolev and built in 1909 by the students of the Moscow Military Technical School under the supervision of N. Ye. Zhukovskiy.

The museum has recently received a whole series of new exhibits including signed testimonials by Sergo Ordzhonikidze, K. Ye. Voroshilov, Henri Barbusse, Wilhelm Pieck and other prominent figures, regarding the work of the Central Aerohydrodynamic Institute.

The glider of Otto Lilienthal, presented by the latter to N. Ye. Zhukovskiy in 1895, has been restored.

The aviation hall has received models of the A. N. Tupolev planes, including the Tu-104 plane, the hydroplanes of G. M. Beriyev and helicopter models.

Much work has been done in unearthing and assembling materials, particularly photographic documents. Dozens of folders, containing testimonials and diplomas presented on various occasions to N. Ye. Zhukovskiy, have just been brought together at the museum.

The exhibits include materials on airship building.

The museum staff is doing research work on the unpublished and little known materials concerning life and activity of N. Ye. Zhukovskiy. At present Nikolay Yegorovich Zhukovskiy's unpublished letters, as well as letters addressed to him have been made ready for the press.

Recently the scientific board of the Central Aerohydrodynamic Institute and the board of the Scientific Memorial Museum held a joint meeting to mark the 110th anniversary of N. Ye. Zhukovskiy's birth. A paper entitled "On Joined Vortexes" dealing with N. Ye. Zhukovskiy's work and its significance in the development of aerodynamics was read by an honored scientist and technician, Prof. F. S. Pyshnov, Lieutenant General of Technical Services.

At the present time a small movie auditorium is being set up, where technical films on aviation will be shown.

V. I. Maslov, Director
N. Ye. Zhukovskiy Scientific Memorial Museum

READERS SUGGEST

EVALUATING THE RECONNAISSANCE QUALITIES OF AERIAL CAMERAS

The relative estimate of photographic equipment in various aircraft of different countries often requires a comparative evaluation of aerial cameras from the standpoint of the effectiveness of their application to aerial reconnaissance.

At the present time separate parameters are compared in the relative estimate of the aerial cameras, permitting only an approximate evaluation of their reconnaissance qualities.

Officer L. T. Safronov proposes a new method of quantitative evaluation for the reconnaissance qualities which, in his opinion, enable one to make a more precise comparative evaluation of them.

The principal requirements put on the reconnaissance aerial cameras are the following. They must photograph in one run the greatest possible area (with a considerable exposure of the terrain in width along the flight route), carry out flight route photography with a required amount of longitudinal overlapping at greatest possible flight speeds, and yield aerial photographs with sufficiently large scale of image in photographing from the greatest flight altitude.

If the aerial cameras satisfy these main requirements, they permit a successful solution of the problem of aerial reconnaissance.

The possibility of photographing a large area in one run of the aircraft leads to a reduction in the number of aircraft sorties for reconnaissance which in turn decreases the probability of combat casualties and reduces the reconnaissance time. Taking of aerial photographs with the necessary image scale (size) and the required longitudinal coverage in photography from high altitudes and high aircraft speeds increases the safety of the reconnaissance flight mission. Therefore it is proposed to take as criteria in making the comparative evaluation of aerial cameras from the standpoint of their application to aerial reconnaissance, parameters which characterize the degree of fulfillment of the main requirements.

The first requirement is the area which can be photographed with a given aerial camera (or an installation consisting of several analogous aerial cameras)

$$Q = AHBpHN, \tag{1}$$

where A is the coefficient of the coverage of the terrain to be photographed, expressed in the units of flight altitude H;

B is the coefficient of the coverage of the terrain along the photographed flight route with the longitudinal overlap equal p (it is also expressed in unit of the flight altitude H);

N is the number of photographs whichcan be taken when the magazine is fully loaded.

The second feature which indirectly characterized the maximum allowable flight speed in photography is the minimum (possible) time T, required to complete-ly use up the supply of film in the magazine, i. e.

$$T = Nt_c \tag{2}$$

where t_c is the time period of camera's operation (minimum time interval between the exposure of neighboring photographs of the flight route).

Eq. (1) divided by Eq. (2) yields the representative quantity - the photographe area per unit time:

$$\frac{Q}{T} = \frac{ABpH^2N}{Nt_c} = \frac{ABpH^2}{t_c}. \tag{3}$$

On the basis of the expression for the numerical map scale, the quantity mf can be substituted for H in Eq. (3), where f is the focal distance of the aerial cam-era, m is the denominator of the map scale, which is taken as unity.

As a result the representative area, photographed per unit time, is expresse as

$$Q_r = \frac{ABpf^2}{t_c}. \tag{4}$$

It cannot, however, fully characterize the reconnaissance qualities of the ae camera, since it does not reflect the altitude at which the camera was used.

Indeed, if Q_r is computed from Eq. (4) for two aerial cameras of the same type, with two different focal distances (for instance for the type AFA 33/20 and A 33/100), identical values of Q_r will result. And, indeed, the possibilities of phot graphing an area per unit time on the same scale is identical for these two camera The reconnaissance qualities are higher in that camera which can photograph the same area, on the same scale, but at a higher flight altitude.

Since the photographing altitude, with the map scales equal, is proportional to the focal distance of the aerial camera one more factor f must be introduced in Eq. (4). Then we finally obtain the coefficient which L. T. Safronov calls <u>the coeff cient of the reconnaissance qualities of the aerial camera:</u>

$$K_r = \frac{ABpf^3}{t_c}. \tag{5}$$

K_r is arbitrarily set for all aerial cameras to be $K_r = 60\%$. Using this coe cient it is possible to make a comparative evaluation of the various aerial camera evaluate the effectiveness of application of aerial cameras of the same type in the ferent versions of installation (AKAFU type, dual), to investigate the ways of inc ing the reconnaissance qualities of the aerial cameras, ets. Let us cite some ex ples. Let us compare the reconnaissance qualities of two aerial cameras, used photography from fighter-interceptors; the AFA-BA/21 and AFA-39.

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The coefficients of reconnaissance quality will be computed from Eq. (5):

for AFA-BA/21

$$K_r = \frac{0.86 \times 0.25 \times 21^3}{1} \approx 2000 ;$$

for AFA-39

$$K_r = \frac{0.8 \times 0.28 \times 10^3}{0.7} = 320 .$$

By comparing the resultant coefficients we can draw the conclusion, that the reconnaissance characteristics of AFA-39 for the same picture quality are considerably below those of AFA-BA/21. However if the aerial negatives obtained with the help of AFA-39 yield a print, after projection printing with 2x enlargement, with the sharpness equal to the sharpness of the contact prints from the aerial negatives, taken with AFA-BA/21, then the effective focal distance of AFA-39 will equal 20 cm. and the computation from Eq. (5) shows for AFA-39:

$$K_r = \frac{0.8 \times 0.28 \times 20^3}{0.7} = 2560 ,$$

i.e. the reconnaissance qualities of AFA-39 in this case become approximately the same as those of AFA-BA/21.

Let us compare the aerial cameras of the types AFA-33/50 m and AFA-39 under the condition that the latter can take aerial negatives from which projection printing with 5x enlargement is possible (with the sharpness of contact prints from aerial negatives taken with AFA-33/50 m).

The coefficient of reconnaissance quality for AFA-33/50 m is equal

$$K_r = \frac{0.6 \times 0.24 \times 50^3}{2} = 9000,$$

and that for AFA-39 with an effective focal distance equal 50 cm.:

$$K_r = \frac{0.8 \times 0.28 \times 50^3}{0.7} = 40,000 .$$

Consequently, AFA-39 under these circumstances possesses markedly higher reconnaissance qualities than does AFA-33/50 m.

Such increase of the reconnaissance quality of AFA-39 is achieved at the expense of a greater photographed area (or a greater size of the enlarged print: 40 x 35 cm. instead of 30 x 30 with AFA-33/50 m) and a smaller period of the aerial camera's operation (0.7 sec. instead of 2 sec. with AFA-33/50 m).

As can be seen from comparison of the reconnaissance coefficients obtained, the solution of the problem of designing photographic systems, which possess sufficiently large terrain coverage coefficients and a very great image sharpness, deserves serious attention.

Quantitative expression of the reconnaissance qualities of aerial cameras with the help of computation of the appropriate coefficients permits a more graphic comparison between them and allows a theoretical evaluation of the effectiveness of the introduction of various design modifications.

NIGHT-TIME ILLUMINATED TARGET ON THE AERIAL BOMBING RANGE

Officer Yu. V. Komissarov proposes a design of an illuminated target to mark it at night (a circle with a diameter 100 m, a cross in the center, of dimensions 40 x 40 m) on the bombing range.

The illuminated night-time target, according to the author, has been successfully used for a year on an aerial bombing range and showed a number of advantages over the previously existing models.

The target is remote-controlled from the command point of the bombing range. It is clearly visible from a great altitude (10,000 - 12,000 m and more) and distance throughout the night (the visibility of torches and bonfires decreases rapidly during the second half of the night). The time spent in the preparation of the target for operation is considerably reduced. In addition there is no need to use fuel for the illumination of the target and for trips taken for repeated refueling and for the preparation of the target for action. Finally, the target is simple in construction, reliable and troublefree in operation.

The proposed target consists of a source of electric power, electrical equipment, electrical wiring and safety wells. To safeguard the wiring from the action of the shock wave and the fragments of the detonated bomb, it is made in two parts: above ground and below ground. The part above ground is made of aluminum or copper wire of 6 mm cross section and is strung on poles from the power source to the target. At a distance to the target of 1000 - 1500 m this part is connected to the part below ground, which is made of two-conductor cable of the type NMH-2 x 2.5 mm rubber covered or of a shielded two-conductor cable. The cable is laid in the trench 1.5 - 2 m deep.

To prevent short-circuits, which can occur as a result of the bomb's explosion a fuse is installed in the sockets of the current distributing device.

The source of electric power is a permanent electric power line or a portable electric generator of 38 kw. power capacity, driven by a diesel motor of 60 h.p. From the power source the current is fed to a control panel at the command point of the bombing range. When the knife switch is closed, the current flows through the current distributing device (Fig. 1a). From there it is conducted to the illumination lights of the target (Fig. 1b). The layout of the equipment and the electrical connection of the lights of the night-time target are given in Fig. 2. The electrical equipment includes current distributing device, illumination lights (28), control panel, and power connector cables (20).

The current distributing device has the function of distributing the electric power, fed from the power source to the illumination lights of the target. The device is an octagonal box of dimensions 60 x 60 x 25 cm with a cover, made from boards, 2.5 cm thick. It is covered with roofing tin for durability and painted with protective color. Inside the box there is a crossbar made of 2 cm boards with two current carrying rings mounted on it: the upper ring being of 25 cm diameter, the lower - 35 cm. The upper ring is 10 cm above the lower one. The rings are made of strips of red copper, 3 cm wide. Twenty-two holes are drilled in each ring and bolts are inserted into these to tie the conductors coming from the sockets. Rubber is inserted for insulation at the points of contact of the rings with the crossbar.

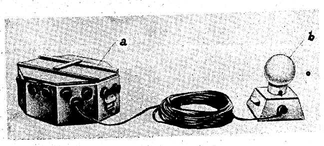

Fig. 1. General appearance of the current switching device and the illuminating lights.

Sockets are fastened to the outside surface of the walls. For convenience in carrying and installing the current distributing device in a well, handles are attached to two walls of the box. The lid is fastened to the box with two latches.

The current distributing device is installed in the center of the target in a special well of dimensions 1.2 x 1.2 x 1.5 m (the inside view of the device is shown in Fig. 3).

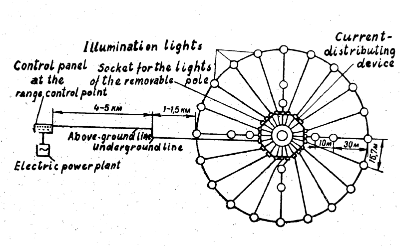

Fig. 2. Layout diagram of the equipment and connections of the electric network of the night-time target.

The illumination light consists of a stand, electric socket, bulb socket and a dome light. An ordinary 40-60 w, 220 volt light bulb is used as a source of light.

The stand for the illuminating light, made of 2 cm boards, consists of four trapezoid-like walls and a cover. The front wall contains a socket, the bulb socket being fastened to the cover by two wooden screws. Wooden handles are put on the side walls of the illumination light for convenience in carrying. In order to install

the illumination light in its operating position, it is necessary to place it in a safety well and connect it to the cable (Fig. 4).

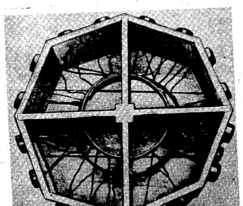

Fig. 3. Inside view of the current distributing device.

The control panel is intended for remote control of the target lights (on and off switching). It is mounted at the control point of the bombing range and represents an ordinary electric panel with a knife switch, fuse and two switches (one for switching on and off the illumination of the working posts at the command point, the second for switching on and off the red signal light on the flagstaff).

Power connector cable of the make NMH-s x 2.5, 52 m long, with male plugs at the ends, feeds the power from the current distributing device to the illumination light.

Depending on the number of illumination lights, which are located in a circle, 20 trenches 1.5 - 2m deep are dug on the range to contain the power connector cables.

The illumination lights, which form the figure of a cross, are connected (in parallel) to the power connector cables, laid along the radial lines of the circle.

The safety well is made of mortared bricks. It protects the illumination light, placed in it, from the explosion of the bomb. In order to increase the resistance of the well to the action of the shock wave, its walls are made in the form of a cylinder. The dimensions of the well are 50 x 50 x 40 cm (inside); the thickness of the brick layer is 15 cm. To provide a passage for the power connector cable and drainage for the rain water, openings are made in the walls and the bottom of the well into which are inserted metal pipes, 4 cm in diameter and 20 cm in length.

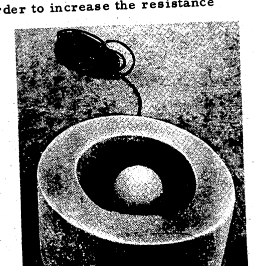

Fig. 4. The illumination light in a safety well.

The safety well is installed on the range in a specially dug pit, which is dug in such a way that the upper part of the well protrudes 5 cm above the ground level. This is necessary to prevent drainage of the rain water into the well.

The safety well for protection of the current distributing device is made analogously, but of larger dimensions.

The current distributing device and the target illumination lights are dismantled and stored in a warehouse after each bombing. Protective wood caps are placed over the male plugs of the power connector cables. After bombing the illumination light wells are covered with lids.

TESTING OF CARBON VOLTAGE REGULATORS WITHOUT THE USE OF A TEST STAND

The parameters of carbon voltage regulators are usually tested on special stands or directly on the aircraft (with the engine running) by listening through earphones to the operation of the regulator. However, in regular units test stands are difficult to build because this requires setting up powerful generators. In order to utilize equivalent generators it would be necessary to rewind the pole windings and to select a supply engine with a wide speed range. While testing carbon voltage regulators directly on the aircraft with a running engine involves a consumption of fuel and engine wear.

Moreover the vary method of testing carbon voltage regulators by listening with earphones is not sufficiently reliable because it contains subjective elements of judgment.

Both methods of testing have a basic fault in common. When determining the fitness of the regulator for further service it is not possible to appraise its work potential (timewise) which is determined by the surface condition of discs of the carbon column.

Engineer Lt.-Col. L. G. Svet proposes a new method of instrument testing of voltage regulators not requiring a test stand. It is commonly known that in the operation of the carbon voltage regulators only one of its parameters varies perceptibly - the resistance of the carbon column $R_{col.}$ This is explained by the fact that the surface of carbon discs deteriorates with time.

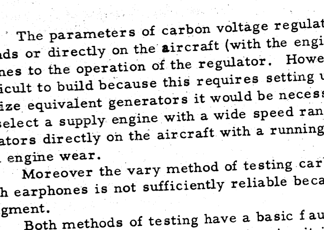

Fig. 1. Curves showing carbon column resistance variation depending on the size of gap δ and current $I_{e.m.}$

Such parameters as the force of the regulator electromagnet and the spring, the elastic reaction of the carbon column depending on the varying size of gap between the armature and core of the electromagnet, are only of theoretical interest. The fact is that under normal conditions obtaining in the unit it is practically impossible to measure them.

Due to design features it is impossible to obtain a performance characteristic of carbon voltage regulators of the type R-25A and RUG-82.

$$R_{col.} = f\,(\delta) \qquad (1)$$

where δ–is the gap between the armature and core of electromagnet.

At the same time it is quite easy to obtain another characteristic

$$R_{col.} = f\,(I_{e.m.}) \qquad (2)$$

where $I_{e.m.}$ is the strength of the current in the coil of the regulator electromagnet, which determines the gap δ as well as the resistance of the carbon column dependent on this gap.

The graphs (Fig. 1) indicate that rating 2 is a reflected image of rating 1.

The relationship of $R_{col.} = f\,(I_{e.m.})$ can be derived from the schematic diagram of Fig. 2.

The rating $R_{col.} = f\,(I_{e.m.})$ was obtained from this schematic diagram for several regulators. A new regulator was conditionally taken as a standard. Its performance curves (Fig. 3) were compared with performance curves of properly functioning regulators mounted in an aircraft, and with faulty ones removed from an aircraft.

Fig. 2. Basic electrical schematic diagram for testing carbon voltage regulators.

Fig. 3 shows the performance curves of several carbon regulators. The probable area within which the curves of properly functioning regulators will fall, is shaded.

The variation of the curves is sufficiently noticeable when the current in the winding of the regulator

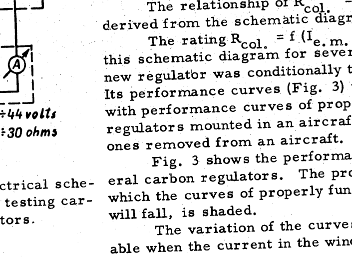

Fig. 3. Performance curves of carbon voltage regulators
1. Performance curve of a new ("standard") regulator
2. Performance curves of faulty regulators.
3. Performance curve of a regulator in good working condition. Area of permissible curve deviation is shaded.

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electromagnet is more than 0.5 amp., and occurs as a result of changes in the surface condition of the carbon discs.

Thus, in order to determine the fitness of a carbon voltage regulator for further use in the aircraft, it is necessary to establish the permissible values of deviation of curves within the working area (the elbow of the curve) and the rigid limits of normal performance area.

It would be desirable to have such control graphs included by the manufacturing plants in the rating record of the carbon voltage regulators.

This would provide a basis for comparison with curves obtained in the course of operation, and for determining the fitness of the regulator for further use.

In the proposed method of testing the regulators there is no need of a preliminary warm-up, for the area of permissible deviation, of control curves may be found even at normal temperature.

The use of a simpler and more convenient method of testing the regulators in the regular units, will make it possible to determine much more accurately and without any costs, the condition of carbon voltage regulators.

DETERMINING THE VERTICAL VELOCITY OF A PILOT BALLOON

At the present time the vertical velocity of a pilot balloon is determined from special tables or an aerological rule from the circumference C and the free lift A of the pilot balloon.

Measuring the circumference under field conditions presents no difficulties, but determining the free lift of the pilot balloon under these conditions is rather difficult. On the open terrain even with the lightest wind, despite careful weighing there is usually an error of 5 - 7 gm.; while with a wind of 4 - 5 m/sec., the error is 10 - 15 gm. This will cause an error in calculating the vertical velocity of the pilot balloon up to approximately 15 - 20 m/min.

Officer M. V. Kolotukhin writes to the editors that the officers of the weather service of the unit X have computed a new table for determining the vertical velocity of a pilot balloon from its circumference and the weight of its skin, using for their computations the same data which was used in compiling the tables in present use.

The following formula is used for this:

$$W = 60\,\pi a\sqrt{\frac{A}{C}}\ .$$

The free lift of the pilot balloon A can be expressed by the following formula:

$$A = V\,(p-y) - q\ ,$$

where V is the volume of pilot balloon
p - air density
y - density of industrial hydrogen
q - weight of skin

(Densities of air and industrial hydrogen are given at +20° temperature and 760 mm pressure).

After substituting for A in the above (derived) expression,

$$W = 60\,\pi a\sqrt{\frac{A}{C}}$$

the formula will appear as:

$$W = 60\,\pi a\sqrt{0.017C^2 \quad (p-y) - \frac{q}{C}}\ .$$

By this formula, substituting different values for C and q, we have computed the table for determining the vertical velocity W of a pilot balloon.

The proposed table is very simple: the column gives the circumference of the pilot balloon C in centimeters; the row gives the weight of skin q in grams, which is stamped on each skin by the manufacturer. At the intersection of values C and q we obtain the vertical velocity of the pilot balloon.

Consequently in order to determine the vertical velocity of the pilot balloon, the weather observer must know the circumference of the pilot balloon and the weight of the skin.

Because the balloon is launched under various weather conditions, and the table is computed for +20 temperature and 760 mm of mercury, it is necessary to introduce correction multipliers (coefficients) for the vertical velocity of the pilot balloon depending on the pressure and the temperature.

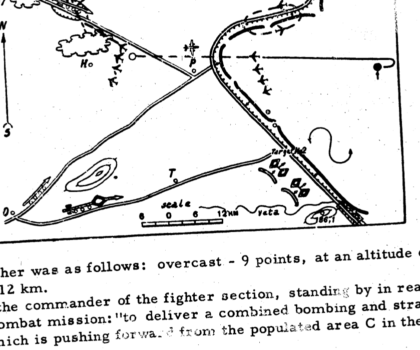
The proposed method has been field tested and gave good results.

WHAT'S YOUR SOLUTION?

WHAT IS THE FLIGHT COMMANDER'S SOLUTION?

The troops of the "Reds" have broken through the enemy defenses with the aid of artillery and air support and are waging a battle along the line shown in the diagram. The "Blues" are hurriedly bringing up their reserves from the depth of defense to the break-through region after having organized an intensive motor transport of troops.

At 0907, the "Red" air reconnaissance had spotted columns of tanks and transport vehicles on the surfaced highways leading to the front line.



The weather was as follows: overcast - 9 points, at an altitude of 5200 m, visibility 10 - 12 km.

At 0920 the commander of the fighter section, standing by in readiness No. 1, received the combat mission: "to deliver a combined bombing and strafing attack on the column, which is pushing forward from the populated area C in the direction of P."

The flight commander knew that two other groups of fighter aircraft will be delivering attacks simultaneously on other transport columns.

He decided to carry out the assigned mission in two passes by forming his flight into a left formation and then by diving from an altitude of 2500 m. The first pass to be made straight-in from the south-east direction, i.e. from the direction of the forest with the attack delivered on the head of the column. Disengagement from the attack to be made with a right turn of 180°. The second pass to be made from the direction of the forest, located farther east of the populated area C, with the break away from the target in the direction of the populated area H and the return to his territory via the shortest route.

At 0932 while approaching the front line at an altitude of 3000 m, the flight commander received a different task: to attack in two passes the target No. 2, i.e. the counter-attacking enemy tanks and infantry.

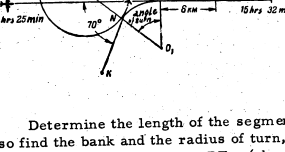
After acknowledging the change-of-target order, the flight commander spotted at the approach to the front line, a group of "enemy" bombers comprising 9 aircraft with fighter escort, flying on a parallel intercept course at a distance of 8 - 10 km and an altitude of 5000 m.

What decision did the flight commander make after he evaluated the newly arisen situation?

COMPUTE THE INTERCEPT MANEUVER

At 1525 the ground controller vectored a fighter to the point A (see Fig.) located ahead of the target at an angle of 70° (CAK) to the line of flight.

The target position for that time was point B. In order to bring the fighter to the rear hemisphere of the target and meet it at 1532 at point F the navigator decided to execute a lag maneuver by making a horizontal turn. Having received the command and the data for the banked-turn, the fighter began a left turn at the point A, and after changing the direction of the turn at point N came out on the line BF at the point D, finding himself 6 km behind the target, on the course equal to that of the target.



Determine the length of the segments AD, BC, and the angle of turn (NO_1D), also find the bank and the radius of turn, if we know that V_f = 720 km/hr and V_t = 540 km/hr and the route segment DE = 6 km (the wind is not taken into account in the calculations).

WHAT WILL HAPPEN TO THE AIRCRAFT?

One of the students reasoned as follows during a lecture. The ground speed W is equal to the geometric sum of the air speed V and wind velocity U. If the ground speed equals zero the aircraft will be motionless with respect to the ground. It follows from this that the sum of the speeds V and U is equal zero, i.e. the plane's air speed V is directed opposite to the wind velocity U and is equal to it in magnitude.

Obviously in this case the lift for such an aircraft "hanging motionless in the air" is produced only by the wind.

Is the student"s conclusion correct?

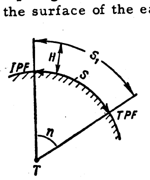
What will happen to the aircraft with ground speed W = 0, if the wind speed momentarily becomes equal to zero?

I SOLVED . . .

ANSWERS TO PROBLEMS PUBLISHED IN NO. 12, 1956 AND NO. 1, 1957

PREPARATION FOR A LONG DISTANCE STRATOSPHERIC FLIGHT

It can be seen from the drawing that the distance S_1 is greater than the distance S, measured on the map by the navigator (along the surface of the earth). Let us determine the required difference $\Delta S = S_1 - S$.



Clearly,

$$S = \frac{2\pi R}{360} n \text{ and } S_1 = \frac{2\pi (R + H)}{360} n.$$

Then

$$\Delta S = \frac{2\pi (R + H)}{360} n - \frac{2\pi R}{360} n = \frac{2\pi H}{360} n.$$

But n is the angular distance between IPF and TPF, which can be easily computed with the help of the relation

$$n = \frac{S}{111},$$

where 111 is the length of arc corresponding to $n = 1^\circ$.

Then finally

$$\Delta S = \frac{2\pi HS}{360 \times 111}$$

With the conditions given in the problem

$$\Delta S = \frac{2 \times 3.14 \times 20 \times 2240}{360 \times 111} \approx 7 \text{ km}.$$

Such an error is not large and it is not worth while to take into account in the preparation for the given flight.

L. M. Vorob'yev

THE NEW YEAR'S PROBLEM

1. The difference between the Khabarovsk and Moscow standard time amounts to 7 hours. The flight lasted 35 minutes less than this difference, consequently 6 hours 25 minutes.
2. The distance from Khabarovsk to Moscow is equal to 6140 km.
3. The average speed of flight is equal to

$$\frac{6140}{6 \text{ hrs. } 25 \text{ min.}} \approx 960 \text{ km/hr.}$$

Yu. G. Mityayev

TWO SOLUTIONS - TWO RESULTS

The actions of the flight commander were incorrect first of all because he had not reconnoitered thoroughly the enemy's river crossing, and had not looked into the possibility of flooding it.

It would have been advisable to attack the vehicles and artillery from a right turn and to break away and return to his territory over the wooded terrain along the shortest route. The approach to the railway station Belaya did not present any danger, since the line was inoperative at a point 30 km from the front line, and consequently was unlikely to be protected by antiaircraft artillery.

The deputy squadron commander had decided correctly to fly the route: airfield - populated area Krasnoye - bend of the river Golubaya - target. In order to insure surprise the target must be approached at low altitude from the direction of the forest with a subsequent climb to 1200 - 1500 m for the dive attack on the crossing. It is also possible to bomb the crossing from a contour flying position with bombs with a slightly delayed time fuse.

In order to overcome the AA fire it is advisable to build the flight's combat formation in two pairs. The first pair follows at a distance of 8 - 12 km and at an altitude of 1800 - 2000 m and their appearance draws the fire of the antiaircraft battery; the second pair delivers the attack. It is better to include in this pair the more experienced pilots who possess thorough bombing training.

L. M. Shishov

SHOULD THE TARGET BE GATED?

It is necessary to plot (construct) the aiming trajectory, along which the fighter flew during the attack in order to solve the problem and to determine the distance D_b at the end of the burst.

The maximum error in the determination of the distance is found in the following way, in case the gating does not take place for the duration of the burst.

$$\frac{D}{D}\,\% = \frac{800 - D_b}{D_b} \times 100 .$$

The distances at the end of the burst, for the given conditions and for different angle-offs and durations of bursts are given in the table:

Distance at the moment of commencement of fire (in m.)	Distance at end of burst (in m.)			
	Angle-off 1/4		Angle-off 3/4	
	burst time 1 sec.	burst time 2 sec.	burst time 1 sec.	burst time 2 sec.
800	770	740	680	610
600	570	550	520	470
400	370	350	340	300

Using this table the pilot can determine whether it is necessary to gate the target during the entire burst under the given firing conditions.

V. M. Baluyev

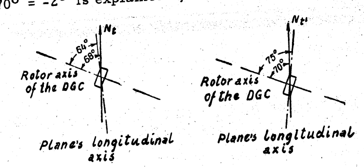
FIND THE ANGULAR VELOCITY OF "RECESSION" OF THE DIRECTIONAL GYRO COMPASS

At 0928 the true course of the aircraft was $TC_1 = 352^\circ - 3^\circ + 7^\circ = 356^\circ$ and the directional gyro compass reading was 64°. Consequently the angle between the rotor axis and the north direction of the true meridian equals $64^\circ + (360^\circ - 356^\circ) = 68^\circ$ (see figure).

The navigator further determined the TC at the time 0958. $TC = 7^\circ + 1^\circ - 3^\circ = 5^\circ$, and the directional gyro compass reading was 75°. Now the angle between the rotor axis of the DGC and the north direction of the true meridian became

$$75^\circ - 5^\circ = 70^\circ .$$

Since the track angle was always equal to 0°, the position of the true meridian with respect to ground did not change during the flight and consequently the difference in angles $68^\circ - 70^\circ = -2^\circ$ is explained by the recession of the rotor axis of the DGC.



This recession was observed over 30 minutes of flight; then the angular velocity of the "recession" of the DGC's rotor axis as found by the navigator is

$$\omega = -\frac{2}{0.5} = -4^\circ/\text{hr}.$$

L. V. Mikhaylov

FROM THE EDITOR'S MAIL

THE ACTIONS OF THE PILOT WHEN HIS COCKPIT CANOPY IS BLOWN OFF IN FLIGHT

Pilot V. G. Maksimov in the front cockpit with instructor G. G. Dan'shin in the rear cockpit were once flying a training combat mission in a trainer aircraft of the type MiG-15. At the moment when the plane pulled out of the dive and started climbing at the speed of 800 - 850 km/hr, the casing of the front cockpit canopy failed. Pilot Maksimov relates that he felt at that moment a powerful blast of air in his face and heavy acceleration stress; he lost his visual perception of the plane's position and ejected. The pilot instructor Dan'shin also could not perceive the spatial position of the plane because of the strong turbulence of the air stream in the rear cockpit and he also ejected.

In evaluating this fact we can say only the following: neither pilot knew the peculiarities of the plane's behavior under these circumstances and reached a hurried and unjustified decision. To prove the point another case may be cited. Pilot Polyanskiy in a similar situation, and also flying in the rear cockpit, did not become confused, but showed resourcefulness and sensible initiative; he reduced the flight speed and safely landed the plane on his airfield. Thus he proved in actual practice that even when the cockpit canopy is blown off in flight, a skillful pilot can land his plane on the airfield.

How should a pilot act when confronted with a similar situation in flight in order to bring the flight to its successful conclusion?

Before answering this question I would like to dwell on two cases which are taken from my own flying experience.

In the first case the front cockpit canopy casing disintegrated at a speed of over 900 km/hr. The failure of the canopy was accompanied by a powerful clap and a partial loss of controllability. Being located in the front cockpit, I leaned closer to the stationary part of the canopy, shifted the throttle control lever to idle and let out the brake flaps. There was no feeling of stress on my body. But it was, nevertheless actually impossible to determine visually the position of the plane in space relative to the true horizon and to the surface of the earth. The aircraft had scarcely changed its direction of flight, but it was rapidly losing altitude with considerable shaking and a bank of the order of 30 - 40° which occurred at the moment of the failure of the canopy; I determined this fact by the indications of the plane; image on the gyro horizon indicator AGI-1, as it appeared on the brown background of the spherical scale of the instrument dial. It was impossible to make out the readings of other instruments because of the aircraft's vibration and the strong air stream. For the same reasons, the intercom contact on the SPU could not be made with the

pilot in the second cockpit.

By referring to readings of the gyro horizon indicator, I moved the controls into the appropriate position in order to bring the plane into level (horizontal) flight. However, for some time (3 - 5 seconds) the plane responded sluggishly and only when the speed dropped down to 800 - 850 km/hr and the altitude had dropped from 7000 to 5000 m was the controllability of the plane fully re-established and the readings of all the flight instruments became clearly visible. In addition it became possible to determine visually the plane's position in space. From then on there was no difficulty in piloting the aircraft.

In the other case, pilot V. I. Shechkov and I were flying a trainer UTI MiG-15 on instruments by the OSP system. I was in the second cockpit. While making a turn to pierce the clouds at the altitude of 250 - 300 m and the speed of 680 - 700 km/hr, we heard a clap and felt an air blast on our faces caused by the blowing off of the front cockpit canopy. At the moment the canopy was blown off Shechkov reduced the engine rpm, removed the bank angle, dropped the speed to 380 - 400 km/hr, and having reported the incident by radio to the command point completed the routine circling flight. During all this time neither the stability nor the controllability of the plane were disrupted. Such correct actions on the part of the front cockpit pilot facilitated the piloting of the plane from the rear cockpit, from the moment the canopy was blown off to the moment of landing.

In the second cockpit the blowing off of the canopy was characterized by more unpleasant effects. The loud clap was also heard here while the blast of air first disrupted visual perception of the instrument readings (altitude, speed). However the dial of the gyro horizon indicator could be read normally. With a slight reduction in speed, i. e., immediately after leveling off into horizontal flight it became possible to make use of other flight instruments in addition to the gyro horizon indicator. Piloting the plane at 350 - 400 km/hr presented no difficulties. The descent after the fourth turn, the calculations and the landing were almost normal, with the exception of some effect of the air stream on the face and eyes.

All these facts lead to the conclusion that the blowing off or unintentional jettisoning of the cockpit canopy in flight or the destruction of its casing, do not in any way provide a reason for immediately abandoning the aircraft, even if for no other reason than the fact that at speeds up to 800 - 850 km/hr the stability and controllability of the aircraft are not affected by the blowing off of the canopy not only in horizontal flight but also in turning, while its position in space may be determined from the readings of the gyro horizon indicator AGI-1. Acting with precision and confidence, the pilot, particularly in the front cockpit, will be able to safely complete his flight independently of the operating conditions of the aircraft, the altitude and the speed at the moment the canopy was blown off.

What actions of the pilot would be correct? In every case the pilot must remain cool and not make any hasty decisions. If the canopy is blown off when the speed is more than 850 km/hr and the aircraft becomes hard for him to control, the pilot in the front cockpit must shift the engine control to idle and release the brake flaps. To lessen the effect of the air stream it is necessary to lean closer to the stationary front section of the canopy and put on the goggles. It is necessary to determine the plane's position in space by the gyro horizon indicator readings and first of all, by the position of the plane's image in relation to the horizon index and the color of the spherical scale. In accordance with the readings of the gyro horizon it is necessary to set the steering controls to a position which will bring the aircraft into level flight. With further reduction in speed, the aircraft must be brought into horizontal flight (again by the gyro horizon readings) and at a speed which will permit the reading of other flight instrument dials the pilot must check and set the aircraft in trim. It is further suggested (if the flight takes place under normal weather conditions) that the plane's position in space be determined visually by reference to the natural horizon, that the speed be reduced to 350 - 400 km/hr by the (airspeed) indicator, and the airfield reached and a landing made. Under these circumstances the turns are banked at no more than 20 - 25^{o}, maintaining strict coordination. Lack of coordination results in slipping and produces strong air turbulence in the rear cockpit, which considerably complicates the piloting of the plane, while in the winter it may even subject the pilot to frostbite.

If the instructor is located in the rear cockpit (in the initial training flights of cadet pilots) he must follow the same sequence of actions as though he were in the front cockpit. When the cadet pilot has had sufficient experience, the instructor's task is reduced to a mere checking of his actions and instrument checking of the plane's position primarily by the readings of the gyro horizon indicator.

In case of the blowing off of the cockpit canopy at speeds below 800 - 850 km/hr, it is also necessary to reduce the speed by the methods described above. After this, the plane is flown on instruments from the front cockpit, while at a speed of about 650 km/hr, the plane is piloted visually. The pilot in the second cockpit flies the plane by the gyro horizon readings to speeds of 500 - 550 km/hr after that by visual reference.

These recommendations also apply completely to the combat planes of similar type.

Military Pilot First Class
Lt. Col. G. G. Semenko

FROM BENCHES TO DIAL PANELS

Lately several articles have been published in this magazine devoted to the use of benches for the maintenance of the aircraft's radio technical equipment, and to the design of such benches. The readers' interest in these questions is not accidental. The point is that modern radio equipment requires a comprehensive testing of all of its parameters. Besides measuring precisely the output parameters, one has to control very carefully the magnitude and the form of the output signals of the intermediate assemblies, whose malfunction cannot always be detected immediately. The installation of the equipment on the planes has become considerably more complicated, and this makes the access to the separate assemblies difficult.

In connection with this it became necessary to have technical equipment with the aid of which it would be possible to test, adjust and tune the station as a whole as well as its every separate assembly. Bench installations are being used for this purpose.

The development of bench installations has in some measure facilitated the process of familiarization with and the operation of radio equipment. The design of bench installations developed chiefly in the direction of their portability, simplicity and versatality. As far as certain isolation existed between individual specialists working in this field, the local working conditions left a marked imprint on the character of many different designs. It is this circumstance probably which is responsible for the difference in the points of view on the design and the purpose of benches.

First of all we would like to point out that the term "field conditions" used by many authors contributing to the periodical is not understood quite correctly. By the possibility of using a bench, an instrument or a device "under field conditions" we mean the possibility of using them for testing the aircraft radio technical equipment directly on the aircraft without dismantling it from its place of installation.

In our opinion it is only this circumstance that should determine the use of testing and measuring devices manufactured by industry as well as by the units themselves, for the radio equipment installed on the planes of the tactical air force. However the only meaning which often attaches to this concept is that they can be used outside of the stationary premises.

For instance, at the Moscow Military District Air Force, the exhibition of innovation projects, benches "suitable for use in field conditions" were demonstrated. They were made in the shape of heavy boxes 1.5 m long, inside of which were assembled equipment units, panels with switching devices, control instruments, measuring equipment, etc.

It is believed that installations of this kind can be effectively used under conditions of stationary location of the unit, in the military school air units, in schools, and the like. This opinion is based on the fact that in these installations the measuring circuits are assembled beforehand, and that putting them in working condition consists only of mounting the equipment to be tested and also due to the fact that the component parts of the bench can be most conveniently laid out during their manufacture. This opinion, from our point of view is erroneous, as the installations of this kind require obligatory dismantling of the radio equipment, a fact which greatly increases the amount of work.

Besides, including them in the complex of panels or other measuring devices puts the installation out of commission if it is necessary to send the instruments to be calibrated, that is, it makes the installation dependable on the technical condition of the instruments and makes its use difficult.

Furthermore, often in evaluating the qualities of the bench, the possibility of its being used as a trainer for air personnel is considered a positive feature. But one cannot agree with this. The development of a trainer bench could be expedient only for acquainting the air personnel with the station, for initial familiarization with the process of switching the station on, tuning and regulating it. It is clear that such an installation cannot be called a trainer. Even the fact that on the marker screen of the radar station's bench installations can be observed local objects, corner reflectors in the form of targets, does not allow us to call the bench a trainer. The disadvantage of these trainers is that while using them one cannot completely imitate the working conditions of the equipment in flight.

Now a few words about the combined and sectional benches.

Among the different models of the benches designed lately many were successful in the sense that they satisfy the operational requirements better.

Experience in operating the benches allows us to draw the conclusion that for testing complex radar installations the most efficient are special benches designed for a definite type of equipment.

In this way one achieves the maximum possible use of the bench, the portability of the equipment and the greatest correspondence of the bench construction to the specific design characteristics of the equipment for which the bench is intended.

It is possible also to use different benches simultaneously, which is especially important in conducting regulations work.

The use of combined stands can be practical for operating a whole complex of equipment designed for a limited task, and whose parts are closely connected among themselves (for instance, the bench for aircraft equipment of the type SP-50). The use of this bench equipment for testing and for qualitative execution of complex regulation operations, makes the task easier in many ways, but it has a number of important disadvantages especially for the front line aircraft. The experience accumulated in testing and repairing of aircraft radio technical equipment, and the quality of equipment with which the Air Force units are armed enable us to solve the problem insuring the operation of technical equipment primarily in a different, more perfected and economical way. We are speaking of test panels or simply panels as they are usually called.

The panels represent devices which can be connected to a radio technical equipment or any of its assemblies. With their aid, and having regular testing or measuring devices on hand, the performance of the whole aircraft radio equipment can be tested, and its parameters measured. The panels are provided with appropriate cables for connecting them to the assemblies in the equipment, and with measuring instruments, and include circuits for imitating the functioning of other assemblies.

The advantages of panels over benches are the small weight of the former, their comparative simplicity, and the possibility of construction with the aid of simple means. But the most important is that they enable to carry out all the work of measuring the parameters, testing, and troubleshooting the faults in the assemblies directly on the aircraft, i. e., under true field conditions.

For comparison we could give the following example.

The weight and volume of all the panels at one of the airborne radar stations equals 15% of the weight and volume of the bench installation of this station; they cost 5 - 7 times less, not to mention the fact that their use leaves the whole of the station free to serve its primary purpose.

At present such panels for the radio technical equipment of the aircraft have been developed, and will be delivered to the units this year. This does not exclude the necessity of further work for improving the developed panels and for designing new ones. This problem is set before both the engineering technical personnel of the combat units and the designers working on aircraft radio technical equipment. The development of panels together with the development of prototypes of aircraft equipment, and the inclusion in their aggregate of devices for testing the performance will greatly improve and facilitate the operation and maintenance of the aircraft's radio technical equipment, will increase its reliability and decrease the amount of maintenance work.

It must be noted that the introduction of panels into practical use does not entirely eliminate the use of benches. Benches will be necessary, for instance, for testing the performance of the equipment after repair, when it has to be examined as a unit. But such utilization of benches will pemit a different approach to the problem of their construction and will make them lighter and more portable.

Engineer Col. A. G. Leontovich

ON THE CONTROL AND MEASURING INSTRUMENTS FOR RADIO EQUIPMENT TESTING

Problems, which fighter aviation and particularly air defense is called upon to solve, require reduction of time and means for the preparation of airplanes for take off to a minimum. It is necessary to use various control and measuring equipments for a high-quality preparation of aircraft radio equipment.

The control equipment possessed by combat units ensures comprehensive testing but much time and work is spent for this purpose. For the preparation of the radio equipment on a plane of the MiG-15 type the following instruments are used: signal generator, wave meter, marker testing device, and others. All of these instruments have great weight and bulk because they are fed by separate battery power supplies. Two men are needed to carry them from one plane to another. Does it pay? Radio equipment in combat units is tested from a start bogie or from an airfield mobile service unit. These sources of energy could fully serve as power supply for the control and measuring equipment. In our opinion it is expedient to set up a mobile installation also for testing the radio equipment as a unit directly on the aircraft. With the aid of such a machine of the airfield universal power supply type it might be possible not only to start the engine and check the electrical system from a ground source of power, but it would also be easy and quick to check the correct performance of radio equipment by means of all the necessary control and measuring instruments and installations. Such a mobile radio laboratory would allow to reduce considerably the time spent on the preflight and postflight preparation and to render the work of radio technicians more productive.

The lack of convenient control and measuring equipment in the units forces one sometimes to use unsuitable instruments, for instance an audio oscillator, recommended by officer N. D. Khramov, (the periodical "Herald of the Air Fleet" No. 9, for 1956). The audio oscillator gives a very superficial picture of the efficiency of the marker radio receiver and of the aircraft radio responder because it is impossible to define on what frequency these instruments operate, which leads to the wrong conclusion regarding the quality of their work.

It is desirable that organizations which develop test equipment should show interest in real conditions of radio equipment preparation for flights in combat units and that they should design devices suitable for use under field conditions.

Senior Technical Lieutenant
I. S. Kirichenko

REVIEW AND BIBLIOGRAPHY

THE AERODYNAMICS OF AN AIRCRAFT WING

"The Aerodynamics of an Aircraft Wing", Ye. Karafoli, Published by the Academy of Sciences of the USSR, Moscow 1956, 479 pp. Price 23r. 85c.

In recent years a great number of national and foreign publications dealing with various problems of aerodynamics have appeared. Modern aerodynamics in itself is such a vast science that it is impossible to cover it, even briefly, in a single book. Therefore, in order to achieve a systematic and full exposition of aerodynamics, one, by necessity, has to limit himself to a small, closely interrelated set of problems. Professor Ye. Karafoli, member of Rumanian Academy of Sciences, in his recently published book, "The Aerodynamics of an Aircraft Wing", deals with the problems of the aerodynamics of a wing moving in an incompressible fluid (i.e., for low speeds when the compressibility of air can be neglected). As is clear from the introduction, this book represents the first part of the author's extensive treatise on the theory of a wing. The second part, of which a Russian edition is to be published, will deal with problems connected with subsonic and supersonic flights.

Professor Karafoli's work bears the marks of a monograph. Together with some findings on the theory of a wing obtained by other workers, there are many generalizations by the author himself. The author's research findings, however, are closely related to the remaining material of the book. Thus, it gives the impression of a logical and complete textbook or handbook.

The book contains analyses of varying degrees of completeness of basic, practically important topics on the ideal incompressible fluid flow over a wing. Whenever possible and expedient, the author gives rigorous steps to the solution of problems. In other cases, where solutions by the modern analytical methods are not feasible, he supplies well substantiated engineering solutions.

It is noteworthy that the author attempts throughout the whole book to present theoretical solutions in a form which is easily usable for practical application. This aspect of the book constitutes its primary value.

The method of conformal mapping is applied to the theory of wing profiles. The theory of the wing of a finite span is based on a vortex lifting line.

We see, therefore, that Karafoli presents the theory of aerodynamics of rather long wings (including the swept-back wings). He devotes but little attention to the short and very short wings, which were extensively investigated after World War II.

In the first chapter there is a brief exposition of basic definitions, concepts and equations of classical hydrodynamics. Next is presented the basic information on the vortex theory. There are also included theorems of hydrodynamics, which are most important for the development of the wing theory, basic methods of conformal mapping, as well as some simpler laminar flows (near the eddies, dipoles, past circular cylinder, etc).

The author deals in detail with the theory of airfoil of an infinite span. He states thoroughly his own general method of constructing wing profiles. This method includes as special cases the Zhukovskiy profile, the Karman-Treftz profiles, Karafoli's profiles with rounded trailing edge, and others. The influence of geometrical parameters of a wing profile on its aerodynamic properties is analyzed on the basis of this theory, and there is also given a method for calculating velocities (and pressures) from the surface of the wing. He also considers a case of arbitrary wing profiles (empirical) and gives methods of computations of a flow past these profiles. There is analyzed in a detailed manner a method of construction of a wing-profile for a given pressure distribution. A description of wing-profiles with deflecting parts is given together with formulae which determines the forces and moments on these parts.

In this book is given a theory of biplane of both finite and infinite span. The interaction between the wings of a biplane is treated in detail, as well as the influence of the dimensions of wings and their relative position. A method of computation of aerodynamic characteristics of biplane wings is also given.

The author gives some methods of computation of a flow over a wing of a particular finite span which are based on a theory of a straight lifting line. Of interest is a method developed by him, which permits easy and rapid solutions to problems for an entire class of wings. However, one harly can agree with the author that "the theoretical formulae are strictly applicable to all practical problems" for wings with spans between 2 and infinity, and that in these cases the influence of the vortices along the chord is negligible, (pages 232 and 233). For the wing spans below 3.5 the application of these formulae introduces a considerable error, especially in the calculation of moment characteristics.

On the basis of a lifting line theory, the author analyzes the flow past the twisted airfoil, deflected wing flaps and ailerons, wings with aileron cut outs, and wings rotating with constant angular velocities about vertical and horizontal axes.

The method derived for the flat wing is also applied to the problem of a flow over the wing with deflected, movable surface over a part of its wing span. This method cannot be considered successful because of the slowness of convergence of trigonometric series at the discontinuities of the variation of an attack angle along the span. It seems to us that such problems are solved more effectively by application of special functions which take into account the peculiarities at the discontinuities of the attack angles.

In the sixth chapter a solution is given of the flow over the wing of a finite span based on the lifting area and on the theory of the potential. Here also are given designs derived by the author for the cases of sliding and swept-back wings. These problems could be reduced to the problems of straight wing which has a corresponding additional twist. The solution is very simple and reduces to a lifting line theory. Besides the design data agree with experimental results which confirms the validity of accuracy of computations for the investigated cases.

This chapter is of special interest to readers since in all the text books on aerodynamics published up to date, the theory of swept-back wing for low speed is

absent.

In Karafoli's work a description of unsteady motion of a wing is given together with solution of a problem of effect of the boundary of a stream of air on a flow near the wing. The solution of these problems is applied to a flow over a wing in the presence of the ground, and to a wing with a cylindrical fuselage, as well as to the influence of an air stream induced by a propeller, and finally to the influence of the wall of the wind tunnel.

The work of Professor Ye. Karafoli, in our opinion, encompasses to varying degrees all the basic problems connected with flow over a wing of an ideal, incompressible fluid. In a number of cases new methods of solutions are given which were derived by the author. Although the book does not fully reflect the present state of the theory of aircraft wing, it will prove to be useful for the students of the military engineering Air Academies and for the researchers in the field of aerodynamics of the wing. This book will also be of interest to engineers, since the author reduces all problems to more or less simple formulae to which numerical methods are easily applied.

Professor, Doctor of Technical Sciences,
Engineer Colonel G. F. Burago,
Candidate of Technical Sciences,
Engineer Major S. I. Kuznetsov

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NEW BOOKS ON AVIATION

THE LIFE OF MILITARY PILOTS

Fighter pilot Sergey Stepanovich Mochalov arrives at an air force unit located not far from the small provincial border city of "X". Thus begins the novel "Pilots", by Gennadiy Semenikhin, devoted to the life and work of Soviet military pilots under peace-time conditions.

Upon completion of his studies at the academy, Mochalov, an experienced combat pilot, was appointed commander of a squadron which had been temporarily under the command of his friend and front-line comrade, Kuz'ma Petrovich Yefimkov, Hero of the Soviet Union. Mochalov settles down to work with great zeal.

He gives particular attention to theoretical studies, whereas his deputy Yefimkov considers that a pilot has no need at all to know theory, the physical essence of phenomena, or to understand formulae and charts, but that it is enough for him merely to know how to pilot a plane. As a result of this, a conflict arises between the friends.

Underestimation of theory soon results in the fact that the famous pilot falls behind the present-day demands placed upon a pilot. He was not able to carry out a training exercise and let the "enemy" escape.

Mochalov sharply criticizes Yefimkov for having fallen behind in theory. The friends quarrel. The censure of his comrades and the influence of the party organization compelled the pilot to give serious thought to the matter and he set about studying (and subsequently enrolled in a correspondence course at the academy).

And now Yefimkov no longer fears bad weather conditions. During a blizzard he takes off to search for Mochalov and his wingman, Spitsin, who had not returned after an air battle with a foreign plane that had violated our border. Yefimkov finds his comrades who had made a forced landing in the mountains. Thus ends "Trial", the first book of the novel.

In the second book, "The Life Line", the plot is developed further. Sergey Stepanovich Mochalov has been appointed regimental commander and Kuz'ma Petrovich Yefimkov, squadron commander. The regiment is sent to a city beyond the Volga, to a retraining center. The pilots worked hard studying new equipment and mastering the combat application of jet aircraft.

Returning to "X", the regiment again became occupied with combat training. As a reward for their progress, they received the honor of taking part in an aerial parade over the Tushino airfield on USSR Air Force Day.

There are many other sub-plots as well in G. Semenikhin's novel - the author describes Pilot Boris Spitsin's love for Natasha Bol'shakova, the regimental club librarian, who subsequently becomes a student at the Moscow Conservatory. He introduces the reader to the work and family life of Pilot Tsygankov. Before the reader pass many heroes of various types: young pilots as well as seasoned commanders.

Some people in the novel are discussed more or less in full, others cursorily. The novel deals with the moral character of Soviet officers, with comradeship and friendship. The work of the pilots and their patriotic service to their native land are well described.

The pilots work hard to master thoroughly the new jet planes. The description of the flights is brisk and vivid. The reader senses, as it were, everything that the pilot feels in the air.

The profession of the pilot, especially of the military pilot, is unusually interesting and fascinating. Consequently our readers welcome with great interest every book that throws light on the life of Soviet aviators.

AERODYNAMIC DESIGN OF HELICOPTERS

The defense industry state publishing house released a textbook by the academician B.N. Yur'ev for higher schools of aviation in which methods of aerodynamic design of a helicopter are stated and materials are given for conducting practical training, laboratory work, course and diploma planning.

The first part of the textbook is devoted to the history of domestic helicopter development. In addition the book gives general information on propellers and their design, helicopter lifting rotors, various aerodynamic designs of helicopters. The author points out the great importance of N.Ye. Zhukovskiy's work and that of his students - V.P. Vetchinkin, G.Kh. Savinin, and others in the development of the theory of propellers.

The theory of propellers in the axial flow is analyzed in the second part of the textbook. On the basis of the law of similarity for propellers, the methods of selection of propellers and the engine in the aerodynamic design for airplane and helicopter are stated. Herein are also stated N.Ye. Zhukovskiy's theory of the perfect propeller and the theory of the specific impulse developed by G.Kh. Sabinin jointly with the author. The theory of the impulse is explained more fully in the textbook. The cited formulas make it possible to define the most important characteristics of the helicopter, the vertical rate of climb, the maximum static altitude, as well as the helicopter performance data during the vertical descent with the engine running or operating under autorotation conditions. The author devotes a separate chapter to problems connected with descent safety, showing various methods of landing, use of the breaking power of the rotor, in landing,and a method for calculating the breaking power.

The third part of the textbook is devoted to the horizontal flight of the helicopter. In its first two chapters are described special aerodynamic features of lifting rotor in oblique flow. Based on the theory of impulse the author derives formulas for calculating the induced velocity in the oblique flow across the propeller, which enables to obtain expressions for the propeller thrust and for the required power. The induced velocity is determined by taking into account the interaction of the propellers with each other (designs of multipropeller helicopters) and by considering the action of the wing on the propeller (for helicopters with wings).

Basic equations of uniform helicopter motions are derived for the aerodynamic designs of helicopters in horizontal flight which enable to make calculations for the helicopter by the thrust or power methods, while the method of calculation does not differ from that which is used for planes. The design of the lifting rotor for which flywheel blade motion is determined in the planes of rotation and swing constitutes a special feature. Due to the fact that at present there exist various helicopter designs, the author analyzes the special design features of co-axial, twin-rotor (tandem and lateral) as well as wing helicopters. Power comparison is also made here between the helicopter and the airplane.

The fourth, and last part of the textbook, is devoted to the classical theory of the lifting rotor. For the lifting rotor with lifting blades coefficients of flywheel motions are derived and the force and moments acting on the blade during a swing are defined. The operation of automatically tilting rotor and its effect on the flywheel motion of propeller blades are examined in a separate chapter.

The textbook gives brief information on the effect of centrifugal and coriolis forces on the blade as well as the degree of balancing of the lifting rotor during operation.

B.N. Yur'ev's textbook is a useful training manual for students of advanced schools of aviation.

TRAINING MANUAL ON AIRCRAFT ENGINES

At the end of last year, the Defense Industry State Publishing House brought out a book called "Control of Gas Turbine and Ram-jet Engines". The book has been approved as a training manual for higher aviation schools.

This textbook gives the basic demands made on the control systems of gas turbine engines; it analyzes questions relating to the selection of control parameters and performance characteristics which are needed under the operating conditions for jet aircraft. Primary consideration has been given to the statics of control of a gas turbine engine. The same performance characteristics are then examined from the point of view of their function for designing control and fuel equipment and a description is given of the properties of gas turbine engines, by which their behavior as an object of control is determined.

The authors have given a brief survey of the general principles of control and their application in the control of gas turbine engines. The diagrams of various regulators were examined in the order reflecting the historical course of development of regulator design. The advantages and shortcomings of various types of regulators are evaluated in accordance with the demands placed upon the regulators of the gas turbine engines. Some typical control diagrams for gas turbine engines are also given.

Basic information has been furnished in the book, concerning the system of control, and also descriptions of its various components.

The fourth chapter deals with the methods for designing and analyzing the dynamic characteristics of the control system for gas turbine engines. An analysis has been given here of questions relating to definition of the concept of stability of the control system, and of those relating to an evaluation of the quality of control and to methods for forming transitional processes.

Then follows a description of the effect of non-linearity of characteristics on the dynamic properties of the control system of gas turbine engines and of non-linear characteristics that are typical for the control system of gas turbine engines; a description of experimental methods of research into control systems that contain non-linear elements. The book cites one of the methods for studying auto-oscillations -- continuous oscillations caused by a non-linear control system, and together with this, some questions are examined which are connected with the stability of this system. At the end of this chapter, there is a discussion of simulation of the processes of control which are an effective means for studying, under laboratory conditions, the dynamics of control of gas turbine engines.

The authors have given a rather detailed account of the effect of the processes in the fuel system on the control of gas turbine engines, and brief information about fuel equipment. They have thrown light on questions concerning elements of the fuel equipment; concerning the demands placed on the fuel equipment; concerning the mutual interrelation of the work of the control and fuel equipment; concerning the jet nozzles of various types of gas turbine engines; concerning the fuel pumps and other elements in the fuel systems of gas turbine engines; concerning the characteristics of fuel pumps; and concerning some properties of the fuels used in gas turbine engines.

The concluding chapters are devoted to the control of acceleration of gas turbine engines and to the special features of control of ram-jet engines.

At the end of the book there is an appendix containing a bibliography on engine control.

A positive feature is the fact that at the end of each chapter there are examples which enable the reader to make a deeper analysis of theoretical premises.

Two general diagrams done in color, give a graphic picture of the complex processes of the control and fuel system of gas turbine engines.

The book will be useful for engineers specializing in the field of aircraft engines.

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AVIATION ABROAD

BOMBS WILL NOT SAVE COLONIALISM

V. A. Burov, G. I. Savin

On 5 November 1956 Wegwood Ben and Collins, members of British Parliament, made public, in the House of Commons, some unusual documents. Here are two of them: "Force is on our side and we shall apply it to the fullest extent if you do not show any meekness. We are going to subject you to bombardment wherever you may be. You must know that your villages will be devastated, your wives and children, your fathers and grandfathers will have to flee from their homes, losing their property. If you do not leave your villages they will be destroyed and your houses turned into ruins. You have sinned in laying your trust in Nasser."

These were the leaflets of the British military command destined to be dropped over the territory of Egypt. The true motives and aims of the Anglo-French-Israeli invasion of Egypt were stated in these leaflets with brutal straight-forwardness.

The program of mass destruction of the peaceful Egyptian population which has been openly proclaimed by the British command, found its complete expression in the piratic actions of the troops of the imperialistic aggressors in Egypt. Of all the types of armed forces, which participated in the hostilities, the invader's aviation has perpetrated the greatest number of crimes against the defenseless civilian population. At the decline of the colonial era the imperialistic air pirates have added a series of new disgraceful pages to the bloody history of colonial wars.

Plans to utilize aviation for the suppression of the national liberation movement of the peoples of the Near and Middle East were in the minds of the imperialists long before their attack on Egypt. A sprawling network of air force bases set up by them on foreign territory, was to serve this aim. An article in the British magazine "Economist" of September 1956 defined the purpose of the British air bases in the Near East by saying that their spearhead must be directed "at the allies of Saudi Arabia," i. e., against Egypt, Syria, Yemen and other countries which have taken the road of independent development.

The nationalization of the Suez Canal company by the Egyptian government has been the pretext for unleashing an imperialistic punitive action against the peoples of the Near East, who are struggling for independence. The Western ruling circles fully realized that this legitimate act of the Egyptian people meant a crushing blow to the entire imperialistic colonial system. Seeking to stop the irrepressible process of the political awakening of the oppressed masses, the forces of aggression and reaction attempted in desperation, to delay by force of arms, the progress of history.

In order to prevent the realization of the nationalization of the Suez Canal,

black mail and other methods of political and economic pressure on the government of Egypt were being applied by the Western powers while the latter were preparing an attack on Egypt.

As the situation in the Near East was becoming more strained, considerable naval and land forces were hastily being shifted to the British and French bases, located near the Suez Canal Zone. The Anglo-French command assigned a special task to aviation. Squadrons of British jet fighters of the "Hunter" type were ready to be shifted to Near East airfields as early as the beginning of August.

The British bombing aviation, based in the Mediterranean Sea area was brought to full strength mainly with front-line jet bombers of the "Canberra" type, with the strategic bombers "Valiant" and "Venom" as well as with the fighters "Meteor" and "Hunter". The French air forces, based on the island of Cyprus, were armed mainly with jet fighters of the "Mystére" type, as well as the planes "Thunderstreak." On board French and British aircraft carriers there were carrier-based fighters "Avenger" and "Corsair". Besides both belligerents had at their disposal a considerable number of helicopters for various assignments.

The aircraft carriers "Arromanche" and "Lafayette" were part of the French Mediterranean squadron, which had sailed from Toulon.

The British aircraft carriers "Albion" and "Eagle" which had been based on Malta, were part of an operational task force of British warships, that had moved to the Eastern sector of the Mediterranean Sea on 29 October. Two other British aircraft carriers "Bulwark" and "Tessies" were also sent to the area where the naval forces of the aggressors were massed. An urgent shifting of French paratroopers from Algiers to the island of Cyprus was begun. On the night of 29 October, the British 16th parachute brigade, which had been acting against the Greek partisans in the mountains of Cyprus, was ordered to stop these operations and to be in readiness for a new combat assignment. This brigade was one of the biggest units of the British army in the Near East. It was specially activated in connection with the preparation of aggression against Egypt.

Thousands of troops, including airborne units, were already in full combat readiness on the islands of Malta and Cyprus by the time of Israel's attack on Egypt which had been undertaken with the full knowledge of the ruling circles of Britain and France and which had been instigated by them. Large striking forces of the Anglo-French aviation began to concentrate openly on the airfields of the Near and Middle East. Small air units were also held in readiness in Jordan and Libya.

General Cately was entrusted with the supreme command of the intervention forces. The British marshal of aviation Barnet was appointed air force commander, the French general Broon was made his deputy. A joint Anglo-French staff was created to coordinate military operations. The overall leadership was in the hands of the British command, because of their "superior knowledge of the area."

The first blow against the peaceloving people of Egypt was struck by the Anglo-French air forces on 31 October. At 7:00 Greenwich time British heavy bombers launched a barbarous attack on the capital of Egypt - the city of Cairo, as well as on Alexandria, Port Said, Suez, Ismailia and other cities.

Thus began the colonizers' undisguised criminal aggression against the freedom-loving people of Egypt. At the same time an imperialistic diversion against socialist Hungary was organized, as well as provocative attacks by fascist pogrommakers on the democratic parties and organizations in France and Italy. Now it is becoming ever clearer that all these criminal acts were being perpetrated within the framework of one monstrous plot of the world imperialistic reaction. This plot was intended to undermine the growing power of the socialist camp, to restore the colonial system and to weaken the democratic forces on an international scale.

The Egyptian government addressed a message to the secretary-general of the UN and to the chairman of the General Assembly stating that the "combined French and British armed forces had launched an attack on the Egyptian people and on their territory; that they had carried out systematic and barbarous air raids on all the Egyptian airfields, and had destroyed their property and caused appalling human losses."

Yet the Anglo-French aggressors went on doing their dirty work regardless of the declaration of the Egyptian government and in spite of the indignation of the democratic world. On 1 November hundreds of British and French aircraft again raided Egyptian cities. On this day the planes of the interventionists dropped their lethal load 21 times on Cairo and three times on Alexandria and on the big cities of the Canal Zone. Among the "military objectives" destroyed by them were a hospital and a mosque in Cairo as well as a residential block in Alexandria. On this day particularly many women had been registered among the victims of the air marauders.

The British magazine "Aeroplane" reported that on 1 November it was mainly the fighter aviation that was operating. They assaulted and bombed the planes and the main airfield installations on nine Egyptian airfields. The magazine points out that besides the land-based aircraft, carrier-borne fighters also took part in the air raids. A squadron of "Venom" fighters which was based on one of the airfields on the island of Cyprus was the first to start the attack at dawn. During this day the Anglo-French air forces made 355 sorties in all.

A correspondent of the magazine "Aeroplane" reports that the planned bombardment of the Cairo airfield (West) was cancelled at the time when the bombers were already in the air, because information had been received that along the roads adjoining this airfield American nationals were moving to be evacuated from Egypt. In connection with this it must be said that the presence of civilian population of Egypt in the zone of the airfields Almaz, Abu-Suveyr, Kabrit and others did not cause the cancellation of the order of the Anglo-French command to bomb them.

On the contrary, during the following night of 2 November the Anglo-French imperialists undertook bombings of Egypt on a still larger scale. The whole night "Valiant" and "Canberra" bombers carried out a special operation pinpointing a target and destroying a broadcasting station located in a densely populated sector of Cairo. In the course of the day of 2 November the air activity was increased with the commitment of new air units: the appearance of French fighter-bombers F-84 "Thunderstreak" (American produced) may be noted. Together with "Sea Hawks", "Avengers," and "Corsairs" they strafed ground targets from low altitudes. The "Hunter" aircraft were used as fighter escort for the tactical bombers "Canberra."

Mass bombings of peaceful Egyptian cities and villages continued during the following days also.

On 4 November an airborne operation was started by the British and French

in the Suez Canal zone.

A correspondent of the magazine "Aeroplane" mentions a few details concerning the landing of airborne force in the Port Said zone. During the airdrop, "Canberras" were used as pathfinders, the fighters "Hunter" covered the landing airborne force in several waves, while the French transport ships "Noratlas" had their own fighter cover. Jeeps and field artillery pieces, together with paratroopers were airdropped from "Hastings" transports. An operational unit of the Anglo-French navy took part in the seizure of Egyptian territory in the Port Said zone. Deck helicopters were used during the landing of marine detachments. According to the magazine "Aeroplane" up to 500 officers and men were landed by these helicopters in 91 minutes. In the opinion of the magazine correspondent the success of the effected airborne operation was achieved as a result of the preliminary elimination of the Egyptian air force and the destruction of airfields; and also as a result of the silencing of the coastal and antiaircraft defenses by the naval aviation. Besides, the success of the operation was further facilitated by the destruction of such vital objectives as the big railway bridge connecting Port Said with the capital.

Nevertheless, the Egyptian troops, supported by the civilian population, offered stubborn resistance to the invaders. The first paratrooper groups dropped on Port Said on the morning of 5 November were completely wiped out in the air and on the ground. Venting their rage on the peaceful population the Anglo-French command ordered a bombardment of Port Said from the sea and from the air. Heavy caliber gun shells from the warships as well as air bombs weighing up to 500 lbs. came down on the city and its suburbs.

Eyewitnesses from Port Said state that this inhuman bombardment caused heavy casualties among the civilian population of the city. The Swedish reporter Anderson estimates that from 7 to 12 thousand Egyptians were killed in Port Said.

Dennis Pitts, correspondent of the English paper "Daily Herald" wrote from Port Said on 8 November: "I have just taken a walk of horror. Dead bodies are lying almost on each street corner. They are loaded on trucks and on special laundry service vehicles. Sobbing women are wandering among the corpses, searching for their dear ones."

Port Said was wrapped in smoke from the conflagration for several days after the troops of the interventionists had occupied it.

Having seized the city waterworks, located to the south of Port Said, the Anglo-French command cut off the water supply to hinder in this way fire-fighting operations and to deprive the population of drinking water.

The AP correspondent, William Mahoni, reported on 11 November from Port Said: "The soldiers of the burial details continue to bury the dead in the city cemetery, located on the Mediterranean Sea shore. Trucks loaded with corpses are arriving constantly."

The miserable attempts of the British and French ruling circles to escape the responsibility for the crimes committed by the armed forces of Britain and France in Egypt are not worth anything in the face of these accusing facts.

One has to be a confirmed hypocrite and liar to declare, after having committed the gravest crimes against humanity, that "the civilian population of Egypt has probably suffered only slight damages and that there are few casualties among them." These are the words of Dickson, British delegate to the UN.

The communique issued by the headquarters of the Anglo-French troops on the island of Cyprus is the height of hypocrisy. It says: "The scrupulous choice of targets for air bombing, made by the allied air force command in order not to endanger the civilian population of Egypt, apparently has no precedent in the history of air offensive."

The blood of Egyptian children, the ruins of Egyptian cities testify ruthlessly to the fact that the Anglo-French pirates did not bother about a "careful choice of targets." Schools, hospitals, mosques and dwellings were subjected to bombardment indiscriminately. Old men, women and children were shot down ruthlessly by the air gangsters with machine guns mounted on helicopters. One hundred persons were killed and forty were wounded during a single air raid on the village of Abu-Zaabal.

Marauding air raids of the Anglo-French air forces were going on even after Britain and France had pledged themselves to a cease-fire. On 7 November, i.e., after the date fixed for the cessation of fire, the interventionists, in violation of their pledge, launched renewed fierce air onslaughts against Cairo and other Egyptian cities.

Side by side with the Anglo-French pirates planes bearing NATO identification marks participated in combat operations over the territory of Egypt. The United States of America supplied Britain and France with these planes. Incidentally, one of such American-produced aircraft, the Hellcat, was shot down by the defenders of Port Said.

The Anglo-French and Israeli aggressors did not succeed in committing their crimes with impunity. Heartened by the support of the public opinion of the entire democratic world, the people of Egypt rose bravely in defense of their country. Egyptian soldiers and civilian volunteers displayed models of fighting spirit and valor, though they suffered acutely from lack of armament. According to eye-witness reports from Port Said, weapons of each fallen Egyptian soldier were immediately picked up by others. Egyptian armed forces and civilian volunteers inflicted considerable losses on the enemy.

The aggressors have suffered in Egypt not only material, but also colossal moral and political losses by imposing themselves before all peace-loving forces as the enemies of peace and as die-hard defenders of colonialism. The aggressors were forced to retreat under the pressure of world public opinion. The peoples of the Soviet Union, of the people's democracies, of all the Arab countries as well as of the member-countries of the Bandung Conference sided with Egypt in her just struggle. They demanded unequivocally a halt to the aggression and the withdrawal of the interventionist troops.

The moral defeat of the Anglo-French invaders was so complete, that some reactionary Western circles failed in their attempt to extricate them. The fact that the USA rejected the Soviet proposal to use force jointly to stop aggression, and the fact that the USA had virtually connived with the interventionists, did not help them either.

The censure of the acts of aggression of the ruling circles of Britain, France and Israel by the democratic world opinion was clearly expressed when the representatives of 65 countries voted at the General Assembly of the UN for an immediate cease-fire and the withdrawal of troops from Egypt. This unanimous protest of the representatives of an overwhelming majority of the world population confirmed the complete bankruptcy of the notorious policy from position of strength to which the Anglo-French imperialists resorted in the hope of arresting the inevitable collapse of the colonial system.

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ON THE USE OF DELAY LINES AS NETWORK ELEMENTS

by

L. E. FRANKS

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Technical Report No. 18

July 29, 1957

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SUMMARY

This study concerns the development of analysis and synthesis techniques for networks containing idealized distributed-constant elements in addition to the usual set of lumped-constant elements having parameters R, L, and C. The idealized distributed element is taken to be a lossless delay line represented by the parameters R_o and T. R_o is the characteristic resistance and T is the electrical length in terms of the time delay between terminal pairs of the delay-line element. Networks consisting of delay lines and lumped elements are called *line-lumped* networks.

Analysis procedures are directed toward finding transfer functions for a network containing an arbitrary interconnection of delay lines and lumped elements. Some matrix methods for finding these transfer functions are presented. The transfer functions are not rational in the complex frequency variable and the usual procedures for transient analysis are not applicable. A method for transient analysis based on the time-series representation is presented. A particularly useful form of the time-series representation is the z-transform, a familiar mathematical tool for the analysis of sampled-data systems.

An examination of the time-domain and frequency-domain response properties of line-lumped networks reveals some characteristics remarkably different from the responses of lumped-element networks. These characteristics are used to advantage in the development of synthesis procedures for approximating a prescribed impulse response by z-transform methods. The z-transform methods are particularly applicable to numerically prescribed data. Special emphasis is given to synthesis of networks having impulse responses of limited time duration.

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I. INTRODUCTION

The mathematical techniques employed in the analysis and synthesis of electrical networks are based on the behavior of hypothetical networks called models or equivalent circuits containing idealized elements for which the electrical quantities are simply related. The most commonly used set of idealized elements for linear networks is, of course, the set of "lumped" elements having parameters R, L, and C, and current and voltage sources whose output is either independent or linearly dependent on the various electrical quantities in the network. The purpose of this study is to investigate the consequences of extending the list of elements to include another type of linear element; namely, an idealized delay line.

There are many advantages to be gained from the development of analysis and synthesis techniques for networks containing an arbitrary interconnection of lumped elements and delay lines. In the first place, many physical networks have a natural occurrence of elements of a distributed nature. Often these distributed elements cannot be adequately represented by a reasonable number of lumped elements. This is especially true in wideband VHF or UHF networks. In servomechanism systems, the presence of transportation lags can be adequately represented in an electrical analogue by delay lines. Also, it is sometimes useful to include delay-line elements in the formulation of equivalent circuits for active elements such as electron or semiconductor devices where transit times are involved.

The development of high-quality artificial delay lines and distributed lines with low phase velocity and high characteristic impedance has made the delay line a feasible element for synthesis of video-frequency networks such as are used in pulse communication and computer systems. It is primarily with these applications in mind that the time-series methods of the following chapters are developed.

Synthesis procedures including the use of delay elements have received little attention. Unfortunately, the tendency is to consider the delay line merely a device which, when properly terminated, will perform the operation of delaying a time function by a prescribed amount. This viewpoint is as limited as that of considering inductors and capacitors merely as devices to perform the operation of differentiation or integration of a time function. Transfer functions associated with networks containing delay lines are a combination of rational and transcendental terms in s. The ordinary procedures for analysis and synthesis are no longer applicable since the transfer function will have an infinite number of poles and zeros in the s-plane. One approach is to approximate the transfer function with a rational function of s. However, for any reasonable degree of accuracy in the approximation, the number of terms in the rational function must be made so large that results are very difficult to obtain. For instance, the design of a particular network may include the use of an artifical delay line constructed from a large number of lumped elements. The only reasonable way to calculate the response characteristics of this network is to represent the artificial line by an idealized delay line. For these reasons it is felt that there exists a need for the development of mathematical techniques for handling the transcendental nature of the transfer function.

The idealization of the delay-line element is an obvious step, very similar to the idealization of an inductor or capacitor. Accordingly, the delay-line element will be considered a section of lossless, non-dispersive transmission line of arbitrary length and characteristic resistance. Hence the parameters of this element will be R_o, the characteristic resistance, and T, the electrical length in terms of time delay. Networks containing an arbitrary interconnection of these idealized delay lines and lumped elements will be referred to as "line-lumped" networks.

Chapters II and III are devoted to methods for analysis of the response of line-lumped networks. Matrix methods for finding the transfer function are presented in Chapter II. The time-series representation for the transient response is described in terms of the z-transform in Chapter III. Chapter IV is a discussion of the response properties of line-lumped networks with emphasis on the properties essentially different from those of lumped-element networks. Some synthesis procedures based on these properties are developed in Chapter V.

II. ANALYSIS OF NETWORKS CONTAINING DELAY LINES

A. DETERMINATION OF THE TRANSFER FUNCTION USING TERMINAL VOLTAGES AND CURRENTS

When a network contains a combination of delay lines and lumped elements, the usual procedure for writing network equations in terms of the self and mutual immittances of a combination of two-terminal elements is no longer applicable. The ideal delay line is a three- or four-terminal element and because of its distributed nature it cannot be reduced to a combination of two-terminal lumped elements. The delay line can, however, be represented in terms of a set of parameters relating terminal voltages and currents. For example, this set of parameters might be the elements of the admittance matrix of the delay line. The general approach to be used here is to consider the distributed and lumped parts of the line-lumped network separately. A matrix representation for each part will be developed such that elementary operations on these matrices will yield a matrix representation for the combined network relating voltages and currents at the available terminals.

Using the two-wire transmission line of Fig. 2.1 as a typical section of delay line, it is convenient to express the voltage across the line as the sum of two traveling waves of voltage, the two waves traveling in opposite directions. Then the voltage and current at any point on the line are given by

$$
\begin{aligned}
v(x,t) &= a\left(t - \frac{x}{v_p}\right) + b\left(t + \frac{x}{v_p}\right) \\
i(x,t) &= \frac{1}{R_o}\left[a\left(t - \frac{x}{v_p}\right) - b\left(t + \frac{x}{v_p}\right)\right]
\end{aligned}
\qquad (2.01)
$$

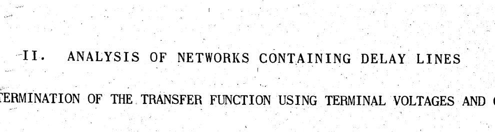

FIG. 2.1.--Traveling waves on a two-wire transmission line.

$$v_n = a_n + b_n; \qquad i_n = \frac{1}{R_o}[a_n - b_n]$$

FIG. 2.2.--Length l of transmission line as a two-terminal-pair circuit element.

where a is the voltage wave traveling to the right with velocity v_p, and b is the voltage wave traveling with velocity v_p to the left. When the delay line is used as a circuit element, only the values of the traveling waves at the terminals are of interest and the words ''right'' and ''left'' have no particular significance; hence it is customary to label the voltage wave incident on the nth terminal pair $a_n(t)$, and the voltage wave reflected from the nth terminal pair $b_n(t)$, as in Fig. 2.2.

It is characteristic of the idealized delay line that neither traveling wave suffers any distortion or attenuation between the terminal pairs except for a time delay. From this the following relations are evident:

$$b_2(t) = a_1(t-T)$$
$$b_1(t) = a_2(t-T) \qquad (2.02)$$

If the network equations were written in the time domain, the result would be simultaneous linear difference-differential equations with constant coefficients. These equations are normally solved by transform techniques. In this discussion, the Laplace transform will be used and all voltages, currents and wave amplitudes will be assumed functions of the complex frequency variable, $s = \sigma + j\omega$. By the shifting theorem, Eq. 2.02 transforms into:

$$B_2(s) = A_1(s)\ e^{-sT}$$
$$B_1(s) = A_2(s)\ e^{-sT} \qquad (2.03)$$

In the formulation of the admittance matrix (short-circuit admittance parameters), the reference node will be assumed to be one of the nodes of the lumped part of the network. For this reason the admittance matrix of the ''superimposed'' distributed part must be written in terms of an arbitrary reference node, so that an arbitrary connection of the terminals of the delay lines to the nodes of the lumped part of the network can be made. At this point it is necessary to distinguish between the balanced delay line and the shielded or unbalanced delay line as a circuit element. This can be done by considering the shielded line a three-terminal circuit element; the voltage at all points on the shield is assumed to be the same. This notation prevents accidental shorting of nodes in the combined network which might occur if the shielded line were considered a four-terminal network as in the case of the balanced line.

It is helpful to note that the sum of the individual columns of the admittance matrix of an n-terminal network (with arbitrary reference node) must be zero. This follows from the fact that the sum of the currents entering the terminals is zero.

$$\sum_{j=1}^{n} I_j = 0 = \sum_{j=1}^{n} \sum_{k=1}^{n} y_{jk} V_k \qquad (2.04)$$

Since Eq. 2.04 must be satisfied for all V_k, then $\sum_{j=1}^{n} y_{jk}$ must vanish for all k. It can also be shown that the sum of the individual rows of the admittance matrix must be zero. If $V_k = V$ for all k, then no current can flow in any of the terminals.

$$I_j = 0 = \sum_{k=1}^{n} y_{jk} V_k = V \cdot \sum_{k=1}^{n} y_{jk} \qquad (2.05)$$

Hence $\sum_{k=1}^{n} y_{jk} = 0$ for all j.

Now the admittance matrix for the shielded line can be determined.

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$$\left.\begin{aligned}
y_{22} &= y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=V_3=0} = G_o \left.\frac{A_1 - B_1}{A_1 + B_1}\right|_{A_2=B_2=0} \\
y_{12} &= y_{21} = \left.\frac{I_2}{V_1}\right|_{V_2=V_3=0} = G_o \left.\frac{A_2 - B_2}{A_1 + B_1}\right|_{A_2+B_2=0} \\
y_{13} &= y_{31} = -y_{11} - y_{12} \\
y_{23} &= y_{32} = -y_{21} - y_{22} \\
y_{33} &= -y_{13} - y_{23}
\end{aligned}\right\} \quad (2.06)$$

Combining Eqs. 2.06 and 2.03, the elements of the admittance matrix are obtained.

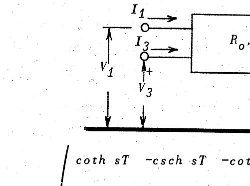
$$\left.\begin{aligned}
y_{22} &= y_{11} = G_o \frac{(A_1 + e^{-2sT}A_1)}{(A_1 - e^{-2sT}A_1)} = G_o \coth sT \\
y_{21} &= y_{12} = \frac{G_o\,(-\,2e^{-sT}A_1)}{(A_1 - e^{-2sT}A_1)} = -G_o \operatorname{csch} sT \\
y_{13} &= y_{31} = G_o(\operatorname{csch} sT - \coth sT) = -\,G_o \tanh \frac{sT}{2} \\
y_{23} &= y_{32} = G_o(\operatorname{csch} sT - \coth sT) = -\,G_o \tanh \frac{sT}{2} \\
y_{33} &= 2G_o \tanh \frac{sT}{2}
\end{aligned}\right\} \quad (2.07)$$

The determination of the 4×4 admittance matrix for the balanced delay line is simplified by consideration of the symmetry properties of a balanced network. These properties require that:

$$y_{11} = y_{33} \qquad\qquad y_{1n} = -\,y_{3n}$$

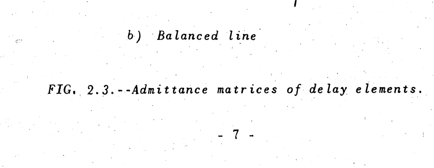
$$y_{22} = y_{44} \qquad\qquad y_{2n} = -\,y_{4n}$$

The property of reciprocity of the delay line requires that $y_{mn} = y_{nm}$. From these relations, the admittance matrix can be written directly. The admittance matrices and terminal designations for the shielded and balanced delay-line elements are shown in Fig. 2.3.



$$\mathsf{Y} = G_o \begin{pmatrix} \coth sT & -\operatorname{csch} sT & -\tanh \frac{sT}{2} \\ -\operatorname{csch} sT & \coth sT & -\tanh \frac{sT}{2} \\ -\tanh \frac{sT}{2} & -\tanh \frac{sT}{2} & 2\tanh \frac{sT}{2} \end{pmatrix}$$

a) Shielded line, $G_o = R_o^{-1}$



$$\mathsf{Y} = G_o \begin{pmatrix} \coth sT & -\operatorname{csch} sT & -\coth sT & \operatorname{csch} sT \\ -\operatorname{csch} sT & \coth sT & \operatorname{csch} sT & -\coth sT \\ -\coth sT & \operatorname{csch} sT & \coth sT & -\operatorname{csch} sT \\ \operatorname{csch} sT & -\coth sT & -\operatorname{csch} sT & \coth sT \end{pmatrix}$$

b) Balanced line

FIG. 2.3.--Admittance matrices of delay elements.

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The admittance matrices of the distributed and lumped networks are combined simply by addition to form the admittance matrix of the line-lumped network. To illustrate this point, suppose a network consists of two inter-connected networks as in Fig. 2.4. The admittance matrices $\mathbf{Y}_1$ and $\mathbf{Y}_2$ are constructed to have a rank of $r + q - p$; where $\mathbf{Y}_1$ has $r - p$ rows and columns consisting only of zeros, $\mathbf{Y}_2$ has $q - p$ rows and columns consisting only of zeros. The p interconnecting nodes must be labeled in such a manner that the node pairs have corresponding positions in $\mathbf{Y}_1$ and $\mathbf{Y}_2$. When the interconnections are made, a network of $r + q - p$ accessible nodes is formed. The external current into the jth node is equal to the sum of the currents in the jth node of the individual networks, hence;

$$I_j = I_{j1} + I_{j2} = \sum_{k=1}^{r+q-p} y_{jk1}V_{k1} + \sum_{k=1}^{r+q-p} y_{jk2}V_{k2}$$

$$= \sum_{k=1}^{r+q-p} (y_{jk1} + y_{jk2})\, V_k, \text{ since } V_k = V_{k1} = V_{k2} \qquad (2.08)$$

So that

$$\mathbf{Y} = \mathbf{Y}_1 + \mathbf{Y}_2$$

If any of the nodes of the distributed part of the network are connected to the reference node of the lumped part of the network, then the row and column of the admittance matrix corresponding to that node can be deleted. This is almost invariably the case when the delay element is a shielded delay line since, if the shield is ungrounded, undesirable stray capacitances to ground are introduced. Thus the admittance matrix for the shielded delay line can usually be written as follows:

$$\mathbf{Y} = G_o\begin{pmatrix} \coth sT & -\operatorname{csch} sT \\ -\operatorname{csch} sT & \coth sT \end{pmatrix} \qquad (2.09)$$

Now that the admittance matrix for the line-lumped network has been determined, transfer functions can be found by the usual application of Cramer's rule for determinants. For instance, the voltage transfer from node l to node m would be given by:

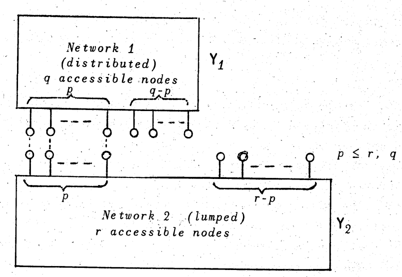
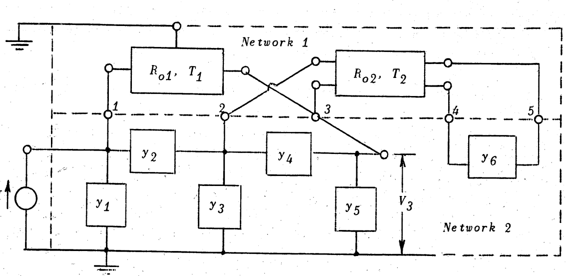


FIG. 2.4.--Interconnection of distributed and lumped networks.



$$\mathbf{Y}_1 = G_{o1}\begin{pmatrix} \coth sT_1 & 0 & -\operatorname{csch} sT_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ -\operatorname{csch} sT_1 & 0 & \coth sT_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} + G_{o2}\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & \coth sT_2 & -\coth sT_2 & -\operatorname{csch} sT_2 & \operatorname{csch} sT_2 \\ 0 & -\coth sT_2 & \coth sT_2 & \operatorname{csch} sT_2 & -\operatorname{csch} sT_2 \\ 0 & -\operatorname{csch} sT_2 & \operatorname{csch} sT_2 & \coth sT_2 & -\coth sT_2 \\ 0 & \operatorname{csch} sT_2 & -\operatorname{csch} sT_2 & -\coth sT_2 & \coth sT_2 \end{pmatrix}$$

$$\mathbf{Y}_2 = \begin{pmatrix} y_1+y_2 & -y_2 & 0 & 0 & 0 \\ -y_2 & y_2+y_3+y_4 & -y_4 & 0 & 0 \\ 0 & -y_4 & y_4+y_5 & 0 & 0 \\ 0 & 0 & 0 & y_6 & -y_6 \\ 0 & 0 & 0 & -y_6 & y_6 \end{pmatrix}$$

$$\mathbf{Y} = \mathbf{Y}_1 + \mathbf{Y}_2$$

$$\frac{V_3}{V_1}(s) = \frac{\Delta_{13}}{\Delta_{11}}$$

FIG. 2.5.--Example of line-lumped network and admittance matrix.

$$\frac{V_m}{V_l}(s) = \frac{\Delta_{lm}}{\Delta_{ll}} \tag{2.10}$$

where Δ_{ij} is the $ijth$ cofactor of the admittance matrix.

To recapitulate, this method for determining transfer functions of line-lumped networks involves the following steps:

(1) The admittance matrix for the lumped part of the network is written with the lines disconnected.

(2) The admittance matrix for the distributed part of the network is written such that the rows and columns of the interconnecting nodes are in correspondence with those of the lumped network matrix.

(3) The two matrices are combined by addition to form the admittance matrix of the combined network.

(4) The desired transfer function is found by the method of determinants. Fig. 2.5 is an example to illustrate these points. Obviously, a similar type of analysis could involve the insertion of terminal pairs of the distributed part of the network into certain loops of the lumped part of the network. Then the impedance matrices of the individual networks would combine by addition to form the impedance matrix of the line-lumped network.

B. DETERMINATION OF THE TRANSFER FUNCTION IN TERMS OF TRAVELING-WAVES

In many cases, especially those in which the line-lumped network is predominantly distributed, the analysis problem is simplified by the consideration of the traveling waves incident and reflected at the various terminal pairs of the network, rather than the terminal voltages and currents. For this purpose, the n-terminal-pair network is considered to be a junction of n delay lines; the relations between the traveling waves on these lines completely determines the electrical characteristics of the junction. As before, the amplitudes of the voltage traveling wave incident and reflected at the kth terminal pair of the junction are represented by A_k and B_k, respectively. Then the terminal voltages and currents are given by:

$$V_k = A_k + B_k$$

$$I_k = \frac{1}{R_{ok}}(A_k - B_k) \tag{2.11}$$

One of the conventional methods of expressing the relations between the traveling waves on the n lines is to write the reflected component at the jth terminal-pair as a linear combination of all the incident components.

$$B_j = \sum_{k=1}^{n} s_{jk}A_k \tag{2.12}$$

or in matrix notation;

$$\mathbf{B} = \mathbf{SA}$$

Eq. 2.12 defines the scattering matrix (S) of the junction or n-terminal-pair network.

The individual elements of the scattering matrix have a simple interpretation. The diagonal elements, s_{kk}, are the reflection coefficients of the kth terminal pair when each of the remaining terminal pairs is terminated in its characteristic resistance so that $A_j = 0$ for $j \neq k$:

$$s_{kk} = B_k$$

when

$$A_j = \delta_{jk}$$

where

$$\delta_{jk} = 1, \; j = k$$

$$\delta_{jk} = 0, \; j \neq k$$

The off-diagonal terms, s_{jk}, are given by the ratio of the wave transmission outward on the jth line to the wave incident on the kth terminal-pair when all lines except the kth are terminated in their respective characteristic resistances:

$$s_{jk} = B_j$$

when

$$A_j = \delta_{jk}$$

The scattering matrix can be expressed in terms of the impedance or admittance (Z or Y) matrices of the n-terminal-pair network.

From Eq. 2.11,

$$V_k + R_{ok}I_k = 2A_k$$

$$V_k - R_{ok}I_k = 2B_k$$

$$V_k = \sum_{l=1}^{n} Z_{kl}I_l$$

In matrix notation:

$$2\mathsf{B} = (\mathsf{Z} - \mathsf{D})(\mathsf{Z} + \mathsf{D})^{-1}2\mathsf{A}$$

where D is a diagonal matrix; $d_{kk} = R_{ok}$

Hence:

$$\mathsf{S} = (\mathsf{Z} - \mathsf{D})(\mathsf{Z} + \mathsf{D})^{-1} \qquad (2.13)$$

Similarly,

$$\mathsf{S} = (\mathsf{D}' - \mathsf{Y})(\mathsf{D}' + \mathsf{Y})^{-1} \qquad (2.14)$$

where D' is diagonal; $d'_{kk} = 1/R_{ok}$

$$\mathsf{D}' = \mathsf{D}^{-1}$$

It follows that

$$\mathsf{Z} = (\mathsf{I} - \mathsf{S})^{-1}(\mathsf{I} + \mathsf{S})\,\mathsf{D}$$

$$\mathsf{Y} = (\mathsf{I} + \mathsf{S})^{-1}(\mathsf{I} - \mathsf{S})\,\mathsf{D}^{-1} \qquad (2.15)$$

Some examples of scattering matrices for relatively simple junctions are shown in Fig. 2.6

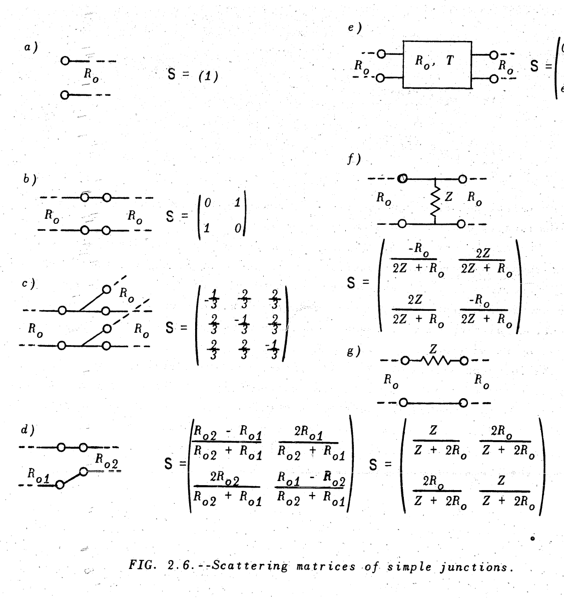


FIG. 2.6.--Scattering matrices of simple junctions.

It is interesting to note the simplicity with which the scattering matrix, S, for an n-terminal-pair junction can be transformed into the scattering matrix, S', for the new junction after the terminals have been moved out a distance l_k on the *kth* line. It is obvious that the incident wave will arrive at the new terminals a time $T_k = l_k/v$ before it arrives at the old terminals, whereas the reflected wave will arrive at the new terminals at a time T_k later. This is expressed in matrix notation as:

$$\mathsf{S}' = \mathsf{PSP} \qquad (2.16)$$

where S is the original scattering matrix and P is a diagonal matrix such that

$$p_{kk} = e^{-(l_k/v)s} = e^{-T_k s}$$

Then:

$$s'_{kk} = s_{kk}e^{-2T_k s}$$

$$s'_{jk} = s_{jk}e^{-(T_j+T_k)s} \qquad (2.17)$$

These relations are often useful in determining the scattering matrix of a predominantly distributed-element network.

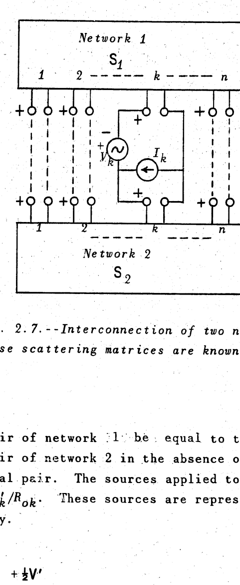
One of the methods for finding a particular transfer function for a line-lumped network is to consider the lumped part of the network as an n-pair junction for which the scattering matrix of rank n can be found. In the combined network, there will be delay lines connected to certain of these junction pairs which will impose constraints on the incident and reflected waves at these junctions. If m junction pairs are constrained in this manner by the interconnection of the delay lines, the scattering matrix of the junction can be reduced to rank n-m corresponding to the remaining junction pairs. By this method the scattering matrix of the line-lumped network could be reduced to a rank of two, corresponding to an input pair and an output pair. The voltage transfer from input to output (open-circuit) would then be given by Eq. 2.18. Since

$$A_2 = B_2$$

$$\frac{V_2}{V_1}(s) = \frac{A_2 + B_2}{A_1 + B_1} = \frac{2B_2}{A_1 + B_1} = \frac{2s_{21}}{(1 + s_{11})(1 - s_{22}) + s_{12}s_{21}} \qquad (2.18)$$

Some of the procedures for systematically reducing the rank of a scattering matrix are presented in Appendix A.

A more straigntforward method for determining the transfer function is developed as follows. The constraints imposed on the incident and reflected components at the junctions by the particular interconnection of the delay lines can all be represented by a single matrix. This matrix is, in fact, the scattering matrix of the distributed part of the network. The voltage and current sources applied to the various terminal pairs can be represented by column matrices. In Fig. 2.7, network 2 would normally contain all the lumped elements of the line-lumped network; network 1 would be the distributed part of the network. The interconnections require that the incident component



$$I_k = \frac{V'_k}{R_{ok}}$$

FIG. 2.7.--Interconnection of two networks whose scattering matrices are known.

at the kth terminal pair of network 1 be equal to the reflected component at the kth terminal pair of network 2 in the absence of voltage or current sources at this terminal pair. The sources applied to the kth terminal pair are V_k and $I_k = V'_k/R_{ok}$. These sources are represented by column matrices, $\mathbf{V}$ and $\mathbf{V}'$, respectively.

Then

$$\mathbf{A}_1 = \mathbf{B}_2 - \tfrac{1}{2}\mathbf{V} + \tfrac{1}{2}\mathbf{V}' \qquad (2.19)$$

$$\mathbf{A}_1 + \mathbf{B}_1 + \mathbf{V} = \mathbf{A}_2 + \mathbf{B}_2 \qquad (2.20)$$

but

$$\mathbf{B}_1 = \mathbf{S}_1\mathbf{A}_1$$

$$\mathbf{B}_2 = \mathbf{S}_2\mathbf{A}_2 \qquad (2.12)$$

So that

$$(\mathbf{I} + \mathbf{S}_1)\,\mathbf{A}_1 + \mathbf{V} = (\mathbf{I} + \mathbf{S}_2)\,\mathbf{A}'_2$$

$$(\mathbf{I} + \mathbf{S}_1)(\mathbf{B}_2 = \tfrac{1}{2}\mathbf{V} + \tfrac{1}{2}\mathbf{V}') = (\mathbf{I} + \mathbf{S}_2)\,\mathbf{A}_2 \qquad (2.21)$$

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Then

$$(\mathrm{I} - \mathrm{S}_1\mathrm{S}_2)\,\mathrm{A}_2 = \tfrac{1}{2}(\mathrm{I} - \mathrm{S}_1)\,\mathrm{V} + \tfrac{1}{2}(\mathrm{I} + \mathrm{S}_1)\,\mathrm{V}' \qquad (2.22)$$

Now Eq. 2.22 can be solved by the usual determinant methods for any of the incident components on network 2 in terms of the sources. In particular, the voltage transfer function from a voltage source across the *lth* pair to the open-circuited *mth* pair is given simply by

$$\frac{V_m}{V_l} = \frac{2A_m}{V_l} = \frac{2\Delta_{lm}}{\Delta_{ll}} \qquad (2.23)$$

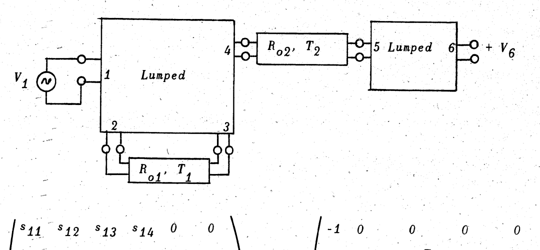
since $A_m = B_m$ and $s_{lj1} = s_{jl1} = \delta_{jl}$; Δ_{ij} is the *ijth* minor corresponding to the determinant of the matrix, $\mathrm{I} - \mathrm{S}_1\mathrm{S}_2$. To illustrate this method of analysis, Fig. 2.8 is given as an example.

C. NETWORKS IN CASCADE

The methods of analysis described so far are completely general in that the transfer function can be found for any arbitrary configuration of lumped elements and delay lines. There is, however, a special configuration frequently encountered in practice whose analysis is considerably simplified by the use of the transmission- or T-matrix. When a number of relatively simple networks are to be connected in cascade, the T-matrix of the cascaded network is the product of the T-matrices of the individual networks. It might be considered the traveling-wave analogue of the general circuit parameters which relate the input and output voltages and currents of a two-terminal-pair network. This approach is especially useful in the case of a transmission line which has lumped loading at discrete points along its length.[1] Also, the method can be extended to include the case of coupled lines where the coupling results from lumped elements connected between the lines at discrete points. Another advantage of this representation is that once two characteristic loading matrices are defined, the T-matrices of the individual networks can be written by inspection.

The T-matrix for a two-terminal-pair network is defined by Eq. 2.24.

[1] W. H. Watson, "*Matrix methods in transmission line and impedance calculations*," Jour. IEE, part III A, vol. 93, 1946. pp. 737-746



$$\mathrm{S}_2 = \begin{pmatrix} s_{11} & s_{12} & s_{13} & s_{14} & 0 & 0 \\ s_{21} & s_{22} & s_{23} & s_{24} & 0 & 0 \\ s_{31} & s_{32} & s_{33} & s_{34} & 0 & 0 \\ s_{41} & s_{42} & s_{43} & s_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{55} & s_{56} \\ 0 & 0 & 0 & 0 & s_{65} & s_{66} \end{pmatrix}; \quad \mathrm{S}_1 = \begin{pmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & e^{-T_1 s} & 0 & 0 & 0 \\ 0 & e^{-T_1 s} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & e^{-T_2 s} & 0 \\ 0 & 0 & 0 & e^{-T_2 s} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & +1 \end{pmatrix}$$

$$\mathrm{I} - \mathrm{S}_1\mathrm{S}_2 = \begin{pmatrix} 1+s_{11} & s_{12} & s_{13} & s_{14} & 0 & 0 \\ -s_{31}e^{-T_1 s} & 1-s_{32}e^{-T_1 s} & -s_{33}e^{-T_1 s} & -s_{34}e^{-T_1 s} & 0 & 0 \\ -s_{21}e^{-T_1 s} & -s_{22}e^{-T_1 s} & 1-s_{23}e^{-T_1 s} & -s_{24}e^{-T_1 s} & 0 & 0 \\ 0 & 0 & 0 & 1 & -s_{55}e^{-T_2 s} & -s_{56}e^{-T_2 s} \\ -s_{41}e^{-T_2 s} & -s_{42}e^{-T_2 s} & -s_{43}e^{-T_2 s} & -s_{44}e^{-T_2 s} & 1 & 0 \\ 0 & 0 & 0 & 0 & -s_{65} & 1-s_{66} \end{pmatrix}$$

$$\frac{V_6}{V_1} = \frac{2\Delta_{16}}{\Delta_{11}}$$

FIG. 2.8.--Example of analysis using scattering matrices.

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$$\begin{pmatrix} B_2 \\ A_2 \end{pmatrix} = \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix} \begin{pmatrix} A_1 \\ B_1 \end{pmatrix} \tag{2.24}$$

If n networks are connected in cascade, then between the networks,

$$\begin{pmatrix} B_k \\ A_k \end{pmatrix} = \begin{pmatrix} A_{k+1} \\ B_{k+1} \end{pmatrix} \tag{2.25}$$

So that

$$\begin{pmatrix} B_n \\ A_n \end{pmatrix} = \prod_{j=1}^{n} \mathsf{T}_j \begin{pmatrix} A_1 \\ B_1 \end{pmatrix} \tag{2.26}$$

The T-matrix can be written in terms of the scattering matrix.

$$\begin{aligned} B_1 &= s_{11}A_1 + s_{12}A_2 \\ B_2 &= s_{21}A_1 + s_{22}A_2 \end{aligned} \tag{2.12}$$

$$\begin{aligned} B_2 &= s_{21}A_1 + \frac{s_{22}}{s_{12}}(B_1 - s_{11}A_1) \\ A_2 &= -\frac{s_{11}}{s_{12}} A_1 + \frac{1}{s_{12}} B_1 \end{aligned} \tag{2.27}$$

Hence:

$$\mathsf{T} = \begin{pmatrix} s_{21} - \dfrac{s_{11}s_{22}}{s_{12}} & \dfrac{s_{22}}{s_{12}} \\ -\dfrac{s_{11}}{s_{12}} & \dfrac{1}{s_{12}} \end{pmatrix} \tag{2.28}$$

When the T-matrix for a cascade of n networks has been found, the voltage transfer function from a voltage source at the first terminal-pair to the open-circuited *nth* terminal-pair can be found in terms of the elements of the T-matrix.

Since $A_n = B_n$

$$\frac{V_n}{V_1} = \frac{2A_n}{A_1 + B_1} = \frac{2(t_{nn}t_{11} - t_{1n}t_{n1})}{t_{nn} + t_{11} - (t_{1n} + t_{n1})} \tag{2.29}$$

To find the characteristic matrix for shunt loading, the T-matrix for the junction of Fig. 2.9 is found.

$$\mathsf{S} = \begin{pmatrix} \dfrac{-y}{y + 2G_o} & \dfrac{2G_o}{y + 2G_o} \\ \dfrac{2G_o}{y + 2G_o} & \dfrac{-y}{y + 2G_o} \end{pmatrix}$$

From Eq. 2.28

$$\mathsf{T} = \begin{pmatrix} \dfrac{2G_o - y}{2G_o} & \dfrac{-y}{2G_o} \\ \dfrac{y}{2G_o} & \dfrac{2G_o + y}{2G_o} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + \frac{y}{G_o} \begin{pmatrix} -\frac{1}{2} & -\frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} \end{pmatrix}$$

$$\mathsf{T} = \mathsf{I} + \frac{y}{G_o} \mathsf{U}_1 \tag{2.30}$$

where

$$\mathsf{U}_1 \triangleq \begin{pmatrix} -\frac{1}{2} & -\frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} \end{pmatrix} \tag{2.31}$$

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This defines the shunt-loading matrix, U_1, and is characteristic of all shunt loading by lumped elements. The series-loading matrix is derived from the junction in Fig. 2.10.

$$\mathsf{S} = \begin{pmatrix} \frac{Z}{Z + 2R_o} & \frac{2R_o}{Z + 2R_o} \\ \frac{2R_o}{Z + 2R_o} & \frac{Z}{Z + 2R_o} \end{pmatrix}$$

$$\mathsf{T} = \begin{pmatrix} \frac{2R_o - Z}{2R_o} & \frac{Z}{2R_o} \\ \frac{-Z}{2R_o} & \frac{2R_o + Z}{2R_o} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + \frac{Z}{R_o} \begin{pmatrix} -\frac{1}{2} & \frac{1}{2} \\ -\frac{1}{2} & \frac{1}{2} \end{pmatrix}$$

$$\mathsf{T} = \mathsf{I} + \frac{Z}{R_o} \mathsf{U}_2 \tag{2.32}$$

$$\mathsf{U}_2 \triangleq \begin{pmatrix} -\frac{1}{2} & \frac{1}{2} \\ -\frac{1}{2} & \frac{1}{2} \end{pmatrix} \tag{2.33}$$

U_2 is the series-loading matrix.

The following matrix product relations between U_1 and U_2 are useful in finding the T-matrix of cascaded networks.

$$\mathsf{U}_1^2 = \mathsf{U}_2^2 = 0 \tag{2.34}$$

$$\mathsf{U}_1\mathsf{U}_2 = \begin{pmatrix} \frac{1}{2} & -\frac{1}{2} \\ -\frac{1}{2} & \frac{1}{2} \end{pmatrix} \tag{2.35}$$

$$\mathsf{U}_2\mathsf{U}_1 = \begin{pmatrix} \frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} \end{pmatrix} \tag{2.36}$$

$$\mathsf{U}_1\mathsf{U}_2 + \mathsf{U}_2\mathsf{U}_1 = \mathsf{I} \tag{2.37}$$

$$\mathsf{U}_2\mathsf{U}_1 - \mathsf{U}_1\mathsf{U}_2 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \tag{2.38}$$

$$\mathsf{U}_1\mathsf{U}_2\mathsf{U}_1 = \mathsf{U}_1(\mathsf{I} - \mathsf{U}_1\mathsf{U}_2) = \mathsf{U}_1 \tag{2.39}$$

$$\mathsf{U}_2\mathsf{U}_1\mathsf{U}_2 = \mathsf{U}_2(\mathsf{I} - \mathsf{U}_2\mathsf{U}_1) = \mathsf{U}_2 \tag{2.40}$$

The network examples of Fig. 2.11 illustrate the analysis procedure.

(a) Π-section lumped loading:

$$\mathsf{T} = (\mathsf{I} + \frac{y}{G_o} \mathsf{U}_1)(\mathsf{I} + \frac{Z}{R_o} \mathsf{U}_2)(\mathsf{I} + \frac{y}{G_o} \mathsf{U}_1)$$

$$= \mathsf{I} + \frac{y}{G_o} \mathsf{U}_1 + \frac{Z}{R_o} \mathsf{U}_2 + yZ\mathsf{U}_1\mathsf{U}_2 + \frac{y}{G_o} \mathsf{U}_1 + \frac{y^2}{G_o^2} \mathsf{U}_1^2$$

$$+ \; Zy\mathsf{U}_2\mathsf{U}_1 + \frac{y^2 Z}{G_o} \mathsf{U}_1\mathsf{U}_2\mathsf{U}_1$$

Now use Eqs. (2.34), (2.37) and (2.39)

$$\mathsf{T} = (1 + yZ)\,\mathsf{I} + \frac{y}{G_o}\,(yZ + 2)\,\mathsf{U}_1 + \frac{Z}{R_o}\,\mathsf{U}_2 \tag{2.41}$$

(b) Section of delay line (R_o, T): By inspection,

$$\mathsf{T} = \begin{pmatrix} e^{-sT} & 0 \\ 0 & e^{sT} \end{pmatrix} \tag{2.42}$$

(c) Delay line junction (change of characteristic resistance):

$$\mathsf{S} = \frac{1}{R_o + R_o'} \begin{pmatrix} R_o' - R_o & 2R_o \\ 2R_o' & R_o - R_o' \end{pmatrix}$$

From Eq. (2.28):

$$\mathsf{T} = \begin{pmatrix} \dfrac{R_o + R_o'}{2R_o} & \dfrac{R_o - R_o'}{2R_o} \\ \dfrac{R_o - R_o'}{2R_o} & \dfrac{R_o + R_o'}{2R_o} \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} \end{pmatrix} + \frac{R_o'}{R_o} \begin{pmatrix} \frac{1}{2} & -\frac{1}{2} \\ -\frac{1}{2} & \frac{1}{2} \end{pmatrix}$$

$$\mathsf{T} = \mathsf{U}_2\mathsf{U}_1 + \frac{R_o'}{R_o}\,\mathsf{U}_1\mathsf{U}_2 \tag{2.43}$$

hence if $R_o' = R_o$,

$$\mathsf{T} = \mathsf{U}_2\mathsf{U}_1 + \mathsf{U}_1\mathsf{U}_2 = \mathsf{I} \tag{2.37}$$

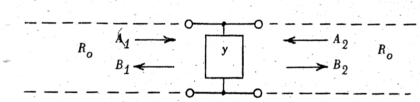


FIG. 2.9.--Lumped shunt loading of a line.

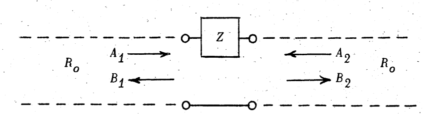
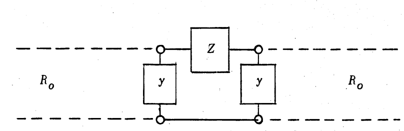
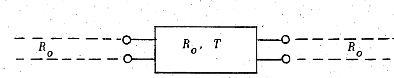


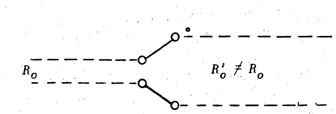
FIG. 2.10.--Lumped series loading of a line.



a) π-section lumped loading.

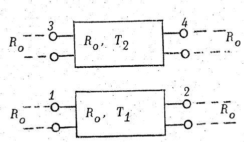


b) Propagation element.



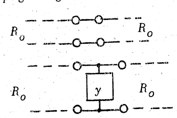
c) Junction of lines of different characteristic resistance.

FIG. 2.11.--Loading and propagation networks.



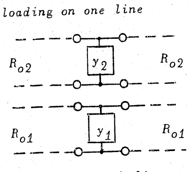
$$\begin{pmatrix} B_2 \\ A_2 \\ B_4 \\ A_4 \end{pmatrix} = \left(\begin{array}{cc|cc} e^{-sT_1} & 0 & 0 & 0 \\ 0 & e^{sT_1} & 0 & 0 \\ \hline 0 & 0 & e^{-sT_2} & 0 \\ 0 & 0 & 0 & e^{sT_2} \end{array}\right) \begin{pmatrix} A_1 \\ B_1 \\ A_3 \\ B_3 \end{pmatrix}$$

a) Two propagating sections.



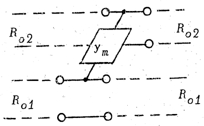
$$T = \left(\begin{array}{c|c} I + \frac{y}{G_o} U_1 & 0 \\ \hline 0 & 1 \end{array}\right)$$

b) Lumped loading on one line



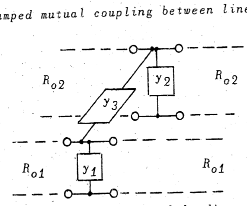
$$T = \left(\begin{array}{c|c} I + \frac{y_1}{G_{o1}} U_1 & 0 \\ \hline 0 & I + \frac{y_2}{G_{o2}} U_1 \end{array}\right)$$

c) Lumped loading on both lines.



$$T = \left(\begin{array}{c|c} I + \frac{y_m}{G_{o1}} U_1 & -\frac{y_m}{G_{o1}} U_1 \\ \hline -\frac{y_m}{G_{o2}} U_1 & I + \frac{y_m}{G_{o2}} U_1 \end{array}\right)$$

d) Lumped mutual coupling between lines.



$$T = \left(\begin{array}{c|c} I + \frac{y_1+y_3}{G_{o1}} U_1 & -\frac{y_3}{G_{o1}} U_1 \\ \hline -\frac{y_3}{G_{o2}} U_1 & I + \frac{y_2+y_3}{G_{o2}} U_1 \end{array}\right)$$

e) Combined self and mutual loading.

FIG. 2.12.--Lines subject to mutual coupling and corresponding T-matrices

The T-matrix representation is also useful when there are two or more cascades of networks with mutual coupling between them. With two parallel lines, the T-matrix is a 4 × 4 matrix which retains the property of combination by multiplication to yield the T-matrix of a cascade of sections on both lines. Fig. 2.12 shows some simple examples

The matrix methods described in this chapter for the analysis of line-lumped networks are by no means the only representations that might be used. The appropriate method depends entirely on the particular configuration of the network to be analyzed. In the case where the network consists predominantly of distributed elements, the scattering matrix approach is preferable since the scattering matrix for a distributed network is easily found. The representation for the overall network is then given by the $(I - S_1S_2)$ matrix. When the line-lumped network consists largely of lumped elements, the admittance matrix approach is preferable. The advantage of T-matrix approach for a cascaded network of lines and lumped elements is obvious. The common feature of all these methods is that the lumped and distributed parts of the network are considered separately and given appropriate matrix representations such that a matrix representation for the overall network is obtained by elementary combinations of these matrices.

III. THE TIME RESPONSE

A. THE EXACT INVERSE TRANSFORM OF THE TRANSFER FUNCTION

The transfer functions found by the methods of Chapter II are the Laplace transforms of difference-differential equations with constant coefficients. The inverse transform is the impulse response of the line-lumped network. These impulse responses have markedly different characteristics from the impulse response of purely lumped-element networks. For this reason it is desirable to study some inversion techniques for transfer functions of line-lumped networks.

The general form of the transfer function can be found from the results of Chapter II to be as given in Eq. 3.01.

$$F(s) = \frac{\sum_{i=o}^{m} A_i(s)\, e^{-sT_i}}{\sum_{j=o}^{n} B_j(s)\, e^{-sT_j}} \qquad (3.01)$$

where the $A_i(s)$ and $B_j(s)$ are rational functions of s. The presence of terms of the form e^{-sT} allows the numerator and denominator of $F(s)$ to have an infinity of roots. $F(s)$ is called a meromorphic function, characterized by the fact that its only singularities in the finite part of the s-domain are isolated poles. The rational function, having a finite number of poles, is a special form of a meromorphic function. A partial fraction representation for a meromorphic function will have an infinite number of terms. If an approximate inversion procedure involves consideration of only a finite number of these terms, this is in effect an approximation by rationalization of the transfer function in the s-domain. This type of approximation will be discussed in Section III-B.

The procedure to be used in this discussion for finding the exact inverse transform of a transfer function makes use of the shifting properties of the operator, e^{-sT}. The shifting theorem is stated in Eq. 3.02. If

$$\mathcal{L}[g(t)] = G(s),$$

Then

$$\mathcal{L}^{-1}[G(s)\, e^{-sT}] \begin{aligned} &= g(t - T) \text{ for } t > T \\ &= 0 \quad \text{ for } t < T \end{aligned} \qquad (3.02)$$

The denominator of $F(s)$ can be expanded, by straightforward division, to the form of Eq. 3.03.

$$\left[\sum_{j=o}^{n} B_j(s)\, e^{-sT_j}\right]^{-1} = \sum_{k=o}^{\infty} C_k(s)\, e^{-sT_k} \qquad (3.03)$$

where

$$T_k = \sum_{j=o}^{n} a_{kj}\, T_j$$

and the numbers, a_{kj}, include all positive integers and zero. Then

$$F(s) = \left[\sum_{i=o}^{m} A_i(s)\, e^{-sT_i}\right]\left[\sum_{k=o}^{\infty} C_k(s)\, e^{-sT_k}\right] \qquad (3.04)$$

$$= \sum_{l=o}^{\infty} D_l(s)\, e^{-sT_l}$$

and

$$T_l = T_k + T_i$$

The division indicated in Eq. 3.03 should be carried out in such manner as to make consecutive terms of the series expansion correspond to successively higher values of T_k. Since the $D_l(s)$ are rational, their inverse transform will be a finite sum of elementary time functions. The total time function will be a sum of functions having rational Laplace transforms but having relative time displacements. By this method, the inverse transform is obtained exactly in terms of a finite sum to some definite value of t. To obtain the time response for larger values of time, more terms in the series representation for $F(s)$ must be inverted. To illustrate the procedure, the voltage across the capacitor in Fig. 3.1a will be found as a function of time when the input end of the line is driven with a step function of voltage.

$$\frac{V_2}{V_1}(s) = \frac{R_o}{R + R_o} \; \frac{\dfrac{2}{1 + R_oCs}\, e^{-sT}}{1 - \left(\dfrac{R - R_o}{R + R_o}\right)\left(\dfrac{1 - R_oCs}{1 + R_oCs}\right) e^{-2sT}}$$

Let $R_oC = 1$ second, $T = 1$ second, $R = R_o/2$, and $V_1(s) = 1/s$, then

$$V_2(s) = \frac{\dfrac{4}{3}\,\dfrac{1}{s(s+1)}\, e^{-s}}{1 - \dfrac{1}{3}\left(\dfrac{s-1}{s+1}\right) e^{-2s}} = \frac{A(s)}{B(s)} \qquad (3.05)$$

$B^{-1}(s)$ can be expanded in a series of powers of e^{-2s}.

$$V_2(s) = \frac{4}{3}\left[\frac{1}{s(s+1)}\right]e^{-s}\left[1 + \frac{1}{3}\left(\frac{s-1}{s+1}\right)e^{-2s} + \frac{1}{9}\left(\frac{s-1}{s+1}\right)^2 e^{-4s} + \frac{1}{27}\left(\frac{s-1}{s+1}\right)^3 e^{-6s} + \cdots\right]$$

$$= \frac{4}{3}e^{-s}\left[\frac{1}{s(s+1)} + \frac{1}{3}\frac{(s-1)}{s(s+1)^2}e^{-2s} + \frac{1}{9}\frac{(s-1)^2}{s(s+1)^3}e^{-4s} + \cdots\right]$$

$$= \frac{4}{3}e^{-s}\left[D_o(s) + \frac{1}{3}D_1(s) + \frac{1}{9}D_2(s) + \frac{1}{27}D_3(s) + \cdots\right] \qquad (3.06)$$

Now the inverse transform can be found term by term.

$$v_2(t) = \frac{4}{3}d_o(t-1) + \frac{4}{9}d_1(t-3) + \frac{4}{27}d_2(t-5) + \frac{4}{81}d_3(t-7) + \cdots \qquad (3.07)$$

$$\left.\begin{aligned} d_o(t) &= 1 - e^{-t} \\ d_1(t) &= -1 + e^{-t}(1 + 2t) \\ d_2(t) &= 1 - e^{-t}(1 + 2t^2) \\ d_3(t) &= -1 + e^{-t}\left(1 + 2t - 2t^2 + \frac{4}{3}t^3\right) \\ d_4(t) &= 1 - e^{-t}\left(1 + 4t^2 - \frac{8}{3}t^3 + \frac{2}{3}t^4\right) \end{aligned}\right\} \begin{aligned} &\text{for } t > 0 \\ &= 0 \text{ for } t < 0 \end{aligned} \qquad (3.08)$$

B. RATIONALIZATION IN THE s-DOMAIN

It is clear that the exact solution for the inverse Laplace transform becomes unwieldy as t increases. Even for moderate values of t, the solution may be the sum of a discouragingly large number of time functions. In many cases where the succeeding time functions converge rapidly to zero, the exact solution up to a given time will be a reasonable approximation for all larger t, and this method of inversion is quite practical.

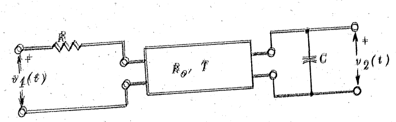
Probably the most obvious approximation to the time response is obtained by approximating the transfer function by a rational function in s. When this is done, the usual inversion techniques for rational Laplace transforms can be applied. This seems to be the classical method of inversion but it suffers some serious drawbacks, as will be pointed out later. A few of the methods for rationalizing meromorphic functions will be discussed here.

1. Truncated Maclaurin series: The expansion about $s = 0$ of e^{-sT} yields the familiar Maclaurin series,

$$(a)\quad e^{-sT} = 1 - sT + \frac{(sT)^2}{2!} - \frac{(sT)^3}{3!} + \frac{(sT)^4}{4!} + \cdots \frac{(sT)^n}{n!} + \cdots$$

$$(b)\quad e^{-sT} = \frac{1}{e^{sT}} = \frac{1}{1 + sT + \dfrac{(sT)^2}{2!} + \dfrac{(sT)^3}{3!} + \cdots \dfrac{(sT)^n}{n!} + \cdots} \qquad (3.09)$$

Termination of the series after a finite number of terms gives a rational approximation to e^{-sT}. For an illustrative example, consider rationalization of the transform of the rectangular pulse function, $p(t) = u_{-1}(t) - u_{-1}(t - T)$.

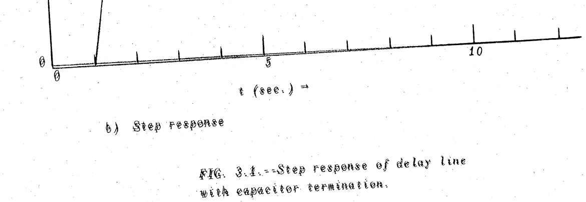


$T = 1$ second

$R_0C = 1$ second

$R = \frac{R_0}{2}$

a) Network



b) Step response

FIG. 3.1.--Step response of delay line with capacitor termination.

$$P(s) = \frac{1 - e^{-sT}}{s} \tag{3.10}$$

Obviously, series (3.09a) is useless. $P^*(s)$ would be a polynomial in s and the inverse would contain only an impulse and its derivatives at $t = 0$. From series (3.09b) approximate with the first four terms of the series;

$$P^*(s) = \frac{1}{s} - \frac{6/T^3}{s(s + \frac{1.6}{T})[(s + \frac{0.7}{T})^2 + (\frac{1.80}{T})^2]}$$

$$p^*(t) = 0.92\ e^{-1.6(t/T)} + 0.86\ e^{-0.7(t/T)} \sin 1.8\frac{t}{T}$$

$$+ 0.08\ \bar{e}^{0.7(t/T)} \cos 1.8\frac{t}{T}$$

This response is shown graphically in Fig. 3.2.

2. Multiple-order pole on real axis: The function e^{-sT} can be represented by the following limit process.

$$e^{-sT} = \lim_{n\to\infty} \left[\frac{1}{1 + \frac{sT}{n}}\right]^n \tag{3.11}$$

Choosing a finite value for n provides the rational approximation by a multiple-order pole at $-n/T$. This method may have the advantage that in some cases factorization of a polynomial in s is not required. The approximation in the time domain to the rectangular pulse function is shown in Fig. 3.3, for $n = 5$.

$$P^*(s) = \frac{1}{s} - \frac{1}{s} \cdot \frac{\left(\frac{5}{T}\right)^5}{\left(s + \frac{5}{T}\right)^5}$$

$$\underset{t>0}{p^*(t)} = e^{-5t/T}\left[1 + \left(\frac{5t}{T}\right) + \frac{1}{2}\left(\frac{5t}{T}\right)^2 + \frac{1}{6}\left(\frac{5t}{T}\right)^3 + \frac{1}{24}\left(\frac{5t}{T}\right)^4\right]$$

3. Padé approximation: The Padé approximation to e^{-sT} is well known in the literature as an attempt to obtain a rational linear-phase filter function. This approximation is appreciably better than that obtained by methods 1 and 2. The Padé approximation involves relating the ratio of two polynominals in s to the Maclaurin series for e^{-sT} in such manner that

$$N(s) - D(s)\,B(s) = \underbrace{0 + 0 + \cdots + 0}_{p\,+\,q\,+\,1 \text{ zeros}} + b_{p+q+1}\, s^{p+q+1} + b_{p+q+2}\, s^{p+q+2} \pm \cdots \tag{3.12}$$

where

$$\frac{N(s)}{D(s)} \doteq \frac{n_o + n_1 s + n_2 s^2 + \cdots + n_p s^p}{d_o + d_1 s + d_2 s^2 + \cdots + d_q s^q}$$

and

$$B(s) = \sum_{k=o}^{\infty} b_k s^k \quad = \left[e^{-sT} \text{ if } b_k = (-1)^k \frac{T^k}{k!}\right]$$

Assuming $q > p$, the following $p+q+1$ linear simultaneous equations result. (There are only $p+q+1$ undertermined coefficients in $N(s)/D(s)$ since d_o can be made equal to unity with no loss of generality.)

$$\begin{aligned}
n_o &= b_o d_o \\
n_1 &= b_1 d_o + b_o d_1 \\
n_2 &= b_2 d_o + b_1 d_1 + b_o d_2 \\
n_3 &= b_3 d_o + b_2 d_1 + b_1 d_2 + b_o d_3 \\
&\;\;\vdots \\
n_p &= b_p d_o + b_{p-1} d_1 + \cdots + b_o d_p \\
0 &= b_{p+1} d_o + b_p d_1 + \cdots\cdots b_o d_{p+1} \\
&\;\;\vdots \\
0 &= b_{p+q} d_o + b_{p+q-1} d_1 \quad \cdots\cdots\cdots\; b_o d_{p+q}
\end{aligned} \tag{3.13}$$

Fortunately, the Padé approximants for e^{-sT} have been tabulated up to fairly large values of p and q.[1] The arbitrariness of the relative degree of the numerator and denominator of the approximant can be used to advantage in specifying the initial behavior of the inverse. If the relative degree of numerator and denominator of a transform is $q - p$, then the first $q-p-1$ derivatives of the inverse will be zero at $t = 0$. Series (3.09a) and (3.09b) are special cases of $q = 0$ and $p = 0$ respectively. Fig. 3.4 shows the pulse function approximation obtained by the use of the Padé approximant ($p = 2$, $q = 4$).

$$P^*(s) = \frac{1}{s} - \frac{1}{s}\left[\frac{1 - \frac{1}{3}(sT) + \frac{1}{30}(sT)^2}{1 + \frac{2}{3}(sT) + \frac{1}{5}(sT)^2 + \frac{1}{30}(sT)^3 + \frac{1}{360}(sT)^4}\right]$$

$$= \frac{1}{s} - \frac{12}{s}\left\{\frac{(sT)^2 - 10(sT) + 30}{[(sT)^2 + 7.56(sT) + 16.2][(sT)^2 + 4.44(sT) + 22.2]}\right\}$$

[1] J. G. Truxal, Control System Synthesis, McGraw-Hill, 1955, p.550.

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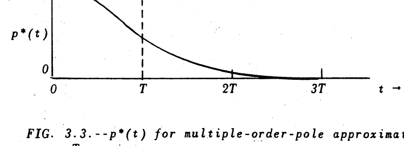


FIG. 3.2.--$p^*(t)$ for Maclaurin expansion of e^{-sT}.

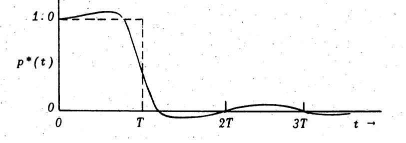


FIG. 3.3.--$p^*(t)$ for multiple-order-pole approximation to e^{-sT}.

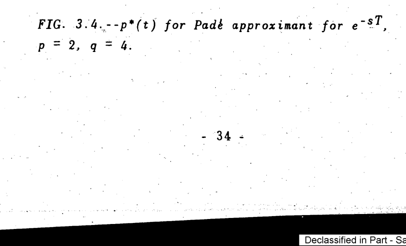


FIG. 3.4.--$p^*(t)$ for Padé approximant for e^{-sT}, $p = 2$, $q = 4$.

$$p^*(t)_{t>0} = e^{-3.78(t/T)}\left[9.5 \sin 1.38 \frac{t}{T} + 2.85 \cos 1.38 \frac{t}{T}\right]$$

$$- e^{-2.22(t/T)}\left[1.53 \sin 4.16 \frac{t}{T} + 1.85 \cos 4.16 \frac{t}{T}\right]$$

4. Mittag-Leffler expansion: A theorem of function theory known as the Mittag-Leffler theorem states that a meromorphic function of the form of Eq. 3.01 can be represented as a series of partial fractions as in Eq. 3.14.

$$F(s) = F(0) + \lim_{N\to\infty} \sum_{n=-N}^{N} \left(\frac{A_n}{s - s_n} + \frac{A_n}{s_n}\right) \tag{3.14}$$

$$0 < |s_1| \leq |s_2| \leq |s_3| - - - - - -$$

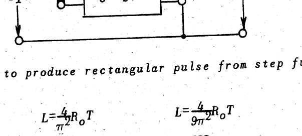
The s_n are the poles of the meromorphic function having residues, A_n. A rational approximation to $F(s)$ is obtained by using only a finite number of terms of the series corresponding to conjugate pole pairs. The utility of this method is severely limited by the difficulty in finding the pole positions. Except in the simplest cases, the location of the pole positions involves the simultaneous solution of a set of mixed algebraic and transcendental equations.

Another rationalization procedure using the Mittag-Leffler expansion, but employing an essentially different network viewpoint, is to derive an approximate equivalent circuit for the terminated delay line consisting of a finite number of lumped elements. Thus, this method performs the rationalization before the transfer function is formed. Zinn[1] and Schelkunoff[2] use the first few terms of the Mittag-Leffler expansion of the driving point immittance of a distributed element with resistive termination to obtain the lumped-element equivalent. From the partial fraction expansion of the immittance function, the Foster canonical form for the lumped-element equivalent can be obtained directly.

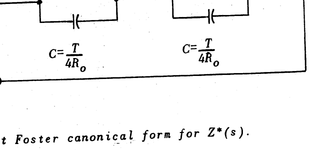
The network in Fig. 3.5 has a rectangular pulse output when driven with a step function voltage input. The input impedance of the short-circuited

[1]M. K. Zinn, *''Network representation of transcendental impedance functions,''* Bell System Tech. Jour., vol. 31, March 1952, pp.378-404.

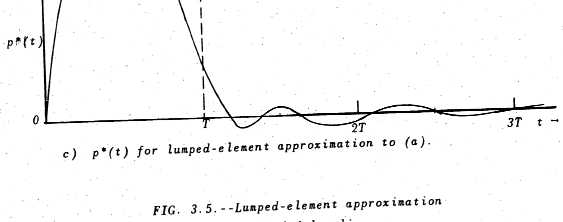
[2]S. A. Schelkunoff, *''Representation of impedance functions in terms of resonant frequencies,''* Proc. IRE, vol. 32, February 1944, pp.83-90.



a) Network to produce rectangular pulse from step function input.



b) First Foster canonical form for $Z^*(s)$.



c) $p^*(t)$ for lumped-element approximation to (a).

FIG. 3.5.--Lumped-element approximation to short-circuited delay line.

line is given by

$$Z(s) = R_o\left[\frac{1 - e^{-sT}}{1 + e^{-sT}}\right] \tag{3.15}$$

Poles of this function occur at $sT = \pm\, j\,(2n - 1)\,\pi$. The residues, a_k, are given by

$$a_k = \left.\frac{p(s)}{q'(s)}\right|_{s=s_k} = \left.\frac{2R_o}{-Te^{-sT}}\right|_{sT=\pm j(2n-1)\pi} = \frac{2R_o}{T}$$

Then the rationalized driving-point impedance obtained by using the first four poles nearest the origin is

$$Z^*(s) \quad \frac{4R_o}{T}\,\frac{s}{s^2 + \left(\frac{\pi}{T}\right)^2} + \frac{4R_o}{T}\,\frac{s}{s^2 + \left(\frac{3\pi}{T}\right)^2}$$

Let $T = \pi$, then

$$P^*(s) = \frac{1}{s}\left[\frac{Z^*(s)}{R_o + Z^*(s)}\right] = \frac{8}{\pi}\left[\frac{(s^2 + 5)}{(s^2 + 1.6s + 1.25)(s^2 + .94s + 7.25)}\right]$$

Then

$$p^*(t) = 2.58e^{-0.8t}\sin\,(0.782t - 0.167) + 0.455e^{-0.47t}\cos\,(2.65t - 0.348)$$

From these results it is apparent that rationalization of the transfer functions in the s-domain results in some serious limitations in obtaining the time response of line-lumped networks. First of all, although the error in approximation of a transfer function by a rational function can be made reasonably small over a large bandwidth, it is not obvious what the corresponding error in the time response will be. The problem of correlation of steady-state and transient approximation errors is well known to circuit theorists and seems not yet to be completely solved. In any case, for reasonably good results the rational approximation must contain a large number of terms thus resulting in unwieldy transfer functions. Furthermore, for a given complexity, it is not

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obvious which of the rationalization procedures should be used for a particular problem. A prominent feature of the rational approximation in the s-domain is the inherent inability to reproduce "echo" type responses in the time domain and hence a rational approximation gives a large error in the time response near a discontinuity removed from the time origin. It is felt that in many cases these disadvantages outweigh the advantage of having a rational transfer function. Indeed, one of the main premises of this study is that the responses of line-lumped networks have distinct characteristics useful for synthesis purposes and that it is not desirable to consider these networks as a special class of lumped-element networks.

C. RATIONALIZATION IN THE z-DOMAIN (TIME-SERIES METHODS)

The rationalization procedures of the preceding section can be manipulated to give a very close approximation to the transfer function of a line-lumped network over a limited region of the spectrum, but the error and error distribution in the time response, resulting from this approximation, is not readily known. It would be desirable to have a mathematical description for time functions from which the behavior of the function in a specific time region could easily be deduced. This would be very useful for synthesis of arbitrary time responses since local error control in a limited time region could be applied.

A time-domain description which has been applied to the analysis of sampled-data control systems (and to a lesser extent in continuous systems) is the time series. An introductory explanation of the time-series representation can be simplified by considering only band-limited time functions. Let $f(t)$ have no spectral components above a frequency Ω. From Shannon's sampling theorem, we know that $f(t)$ can be represented exactly by a series of pulses of the form $(\sin t)/t$ delayed by a time interval, $\tau = \pi/\Omega$, as shown in Eq. 3.16.

$$f(t) = \sum_{k=-\infty}^{\infty} a_k \frac{\sin \Omega(t - k\tau)}{\Omega(t - k\tau)} = \sum_{k=-\infty}^{\infty} a_k \frac{\sin \frac{\pi}{\tau}(t - k\tau)}{\frac{\pi}{\tau}(t - k\tau)} \tag{3.16}$$

The sequence,

$$- - - - a_{-1},\ a_0,\ a_1,\ a_2,\ - - - - a_k,\ - - - - \tag{3.17}$$

contains all the necessary information about the time function except the bandwidth, Ω. This sequence is called the time series for $f(t)$. The individual

elements of the sequence are called the sample values and the time displacement between succeeding pulses, τ, is called the sampling interval. Note that the kth pulse is zero at all other sampling instants so that the value of $f(t)$ at $t = k\tau$ is independent of all pulse magnitudes except the kth.

Addition and subtraction of two time functions corresponds merely to addition and subtraction of corresponding elements of their time series. Another important linear operation with time functions is convolution. Convolution of two time functions, $f(t)$ and $g(t)$, is represented by Eq. 3.18.

$$y(t) = f(t) * g(t) = \int_{-\infty}^{\infty} f(\sigma)\, g(t - \sigma)\, d\sigma \tag{3.18}$$

A physical interpretation of the above operation is that $y(t)$ is the output of a linear filter having an impulse response, $g(t)$ and driving force, $f(t)$. The outstanding feature of time series operations is that convolution of two time functions corresponds to serial multiplication of their time series. To show this, we recognize that the convolution of two of the $(\sin t)/t$ pulses yields a pulse of the same form with a magnitude equal to the product of the magnitudes of the individual pulses. Convolution can be performed with each component pulse of $f(t)$ separately and the final result is obtained by superposition.

$$f(t) * g(t) = \int_{-\infty}^{\infty} \sum_{j=o}^{\infty} a_j \frac{\sin \frac{\pi}{\tau}(t - j\tau)}{\frac{\pi}{\tau}(t - j\tau)} \cdot \sum_{k=o}^{\infty} b_k \frac{\sin \frac{\pi}{\tau}(t - k\tau - \sigma)}{\frac{\pi}{\tau}(t - k\tau - \sigma)}\, d\sigma$$

$$= a_o \sum_k b_k \frac{\sin \frac{\pi}{\tau}(t - k\tau)}{\frac{\pi}{\tau}(t - k\tau)} + a_1 \sum_k b_k \frac{\sin \frac{\pi}{\tau}(t - k\tau - \tau)}{\frac{\pi}{\tau}(t - k\tau - \tau)} + a_2 \sum_k b_k \frac{\sin \frac{\pi}{\tau}(t - k\tau - 2\tau)}{\frac{\pi}{\tau}(t - k\tau - 2\tau)} + - -$$

$$= \sum_j a_j \sum_k b_k \frac{\sin \frac{\pi}{\tau}[t - (k + j)\tau]}{\frac{\pi}{\tau}[t - (k + j)\tau]} = \sum_m c_m \frac{\sin \frac{\pi}{\tau}(t - m\tau)}{\frac{\pi}{\tau}(t - m\tau)} \tag{3.19}$$

where

$$c_m = \sum_{r=o}^{m} a_r\, b_{m-r} \tag{3.20}$$

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It should be noted that the sample values for the convolution product are the same as the coefficients of the product of two polynomials whose coefficients are the sample values of the convolved time functions.

$$(a_o + a_1x + a_2x^2 + - - - a_px^p)(b_o + b_1s + b_2x^2 + - - - b_qx^q)$$

$$= a_ob_o + (a_1b_o + a_ob_1)\ x + (a_2b_o + a_1b_1 + a_ob_2)\ x^2 + - - - + a_pb_qx^{p+q} \tag{3.21}$$

This polynomial representation will be found to be very important later as the connecting link between the time series and the Laplace transform of a time function.

The inverse convolution, e.g., to find the time series for $g(t)$, given the time series for $y(t)$ and $f(t)$ in Eq. 3.18, is performed simply by serial division, analogous to the quotient of two polynomials.

Analysis by time-series methods can represent a considerable time saving since the necessity of performing the tedious task of factoring a large-order polynomial in s and adding the inverse transforms of the partial fractions is avoided. Furthermore, the time series operations are directly applicable to digital computer techniques or other methods of numerical analysis.

Obviously, physical systems cannot be band-limited. A time function with a finite bandwidth cannot be identically zero over a finite (or infinite) interval. Conversely, the time functions relevant to the analysis of physical networks must be zero for all $t < t_o$, hence their spectra must have infinite bandwidth. In order to maintain an exact time series representation, the sampling interval would have to be made vanishingly small, thus making the time-series and continuous-function representations indistinguishable. To preserve the utility of the time-series method, an approximate representation is obtained by letting $\Omega \to \infty$ but retaining a finite sampling interval, τ. This operation results in an impulse sequence for which the area of the kth impulse is equal to the kth sample value. The sequence of the coefficients of the unit impulse functions is still the time series for $f(t)$ and as such is not an approximate but only incomplete representation for $f(t)$; the time series gives no information about the inter-sample behavior of the function as it did in the case of band-limited functions. On the other hand, the sequence of impulse functions, $f^*(t)$, is an approximation to $f(t)$.

$$f^*(t) = \sum_{k=o}^{\infty} f(k\tau)\ u_o\ (t - k\tau) = \sum_{k=o}^{\infty} a_k\ u_o(t - k\tau) \tag{3.22}$$

If it can be established that the spectral components above a radian frequency Ω involve a negligible contribution to the time function, then the approximation $f^*(t)$ can be considered a good one if the sampling interval is taken to be $\tau \leq (\pi/\Omega)$. Decreasing the sampling interval always improves the approximation, but in the interest of economy in the time-series representation, the sampling interval will be chosen as large as possible.

The Laplace transform of $f^*(t)$ is easily found. From Eq. 3.22

$$\mathcal{L}[f^*(t)] = \sum_{k=o}^{\infty} f(k\tau)\ e^{-sk\tau} = \sum_{k=o}^{\infty} a_k e^{-sk\tau} \tag{3.23}$$

Eq. 3.23 is given in a more convenient form by transformation,[1] $z = e^{-s\tau}$. The resulting $F^*(z)$ is called the z-transform of $f(t)$.[2]

$$F^*(z) = \sum_{k=o}^{\infty} a_k z^k \tag{3.24}$$

$$= a_o + a_1z + a_2z^2 + a_3z^3 + a_4z^4 + - - - -$$

Notice the important fact that the coefficients in the power series in z for $F^*(z)$ are the sample values for $f(t)$. Hereafter we shall refer to the z-transform of a time function rather than its time series.

If a time function has a rational Laplace transform, its z-transform can be expressed in closed form. It will be shown that a very simple relationship exists between the partial-fraction expansion of the Laplace transform and the partial fraction expansion of the z-transform. The sample values of the simple exponential time function of Fig. 3.6 are

$$1,\ e^{-\alpha\tau},\ e^{-2\alpha\tau},\ e^{-3\alpha\tau},\ e^{-4\alpha\tau},\ - - - - \tag{3.25}$$

Hence, the z-transform is

$$F^*(z) = 1 + e^{-\alpha\tau}z + e^{-2\alpha\tau}z^2 + e^{-3\alpha\tau}z^3 + - - - - \tag{3.26}$$

This is a power series in $e^{-\alpha\tau}z$ with unit coefficients. The closed form of this series is recognized to be

---

[1] Several authors use $z = e^{s\tau}$.

[2] The star denotes that the z-transform of a sampled time function has been taken. If the actual time function is an impulse sequence, the star will be omitted from the z-transform.

$$F^*(z) = \frac{1}{1 - e^{-\alpha\tau} z} = \frac{-e^{\alpha\tau}}{z - e^{\alpha\tau}} \tag{3.27}$$

But the Laplace transform of this time function is

$$F(s) = \frac{1}{s + \alpha} \tag{3.28}$$

The terms in Eqs. 3.27 and 3.28 are typical terms of a partial-fraction expansion of the Laplace transform and the z-transform. The same correspondence exists if α is complex, so the z-transform of a time function can be obtained directly from the Laplace transform. The correspondence between transforms for multiple-order poles is derived in Appendix B. The z-transforms and Laplace transforms for several time functions are listed in Table I, on page 48

The question of intersample behavior of $f(t)$ for a given $F^*(z)$ can best be studied by considering the implications of the transformation, $z = e^{-s\tau}$. The imaginary axis of the s-plane maps into the unit circle in the z-plane as shown in Fig. 3.7. The region outside the unit circle corresponds to the left-half plane of s, hence the z-transform of a stable time function will have its poles on or outside the unit circle. The correspondence between the s- and z-planes is not one-to-one. For instance, the pole at $z = a$ maps into the infinite number of poles in s at $-1/\tau \log a \pm j\ 2n\pi/\tau$ rad/sec. The whole z-plane maps into an infinite horizontal strip of width $2\pi/\tau$ rad/sec. in the s-plane. For any single-valued $Q(z)$, the corresponding $R(s)$ will be periodic along any line $Re\ s$ = constant. In particular, the spectrum of the impulse sequence, $f^*(t)$, is always periodic.

There are an infinite number of continuous time functions having the same sample-value representation, $f^*(t)$, and hence the same z-transform, $F^*(z)$. Obviously, any time function having zeros at the sampling points can be added to another time function having the correct sample values, yielding a time function with the same z-transform. This non-uniqueness in the inverse z-transform is illustrated in Fig. 3.8. These wildly varying oscillations in the intersample region of a time function cannot be tolerated for analysis purposes. It would be desirable to have an assurance that the interpolation between sample values of a time function is relatively ''smooth'' so that the intersample behavior could be easily sketched. This can always be accomplished by making the sampling interval sufficiently small. In choosing a suitable value for the interval, τ, it is helpful to examine the pole-position

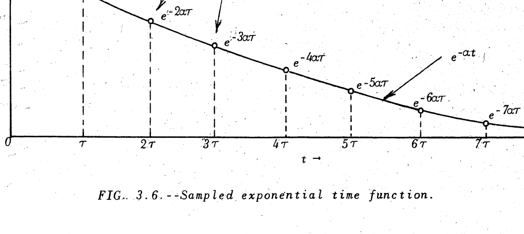

FIG. 3.6.--Sampled exponential time function.

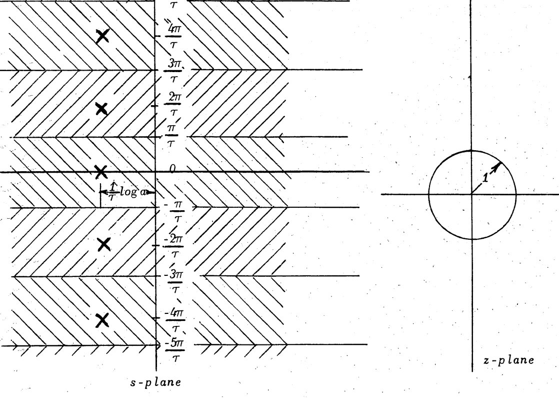

FIG. 3.7.--The transformation $z = e^{-s\tau}$

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loci in the z-plane and in the $s\tau$-plane as τ is decreased. These are shown in Fig. 3.9 for a time function whose Laplace transform has a complex-conjugate pole pair. As τ decreases indefinitely, the pole and zero positions converge toward the point $z = 1$

One criterion for the maximum sampling interval is to require that all poles in the z-plane lie within a region sufficiently close to the point $z = 1$. If the angle of the pole positions is required to be less than ϕ, then each sinusoid will have at least $2\pi/\phi$ samples per cycle. For highly damped functions it is desirable also to restrict the radial distance of the poles from the origin. If the poles are restricted to the range, $1 \leq |z| < R$, Then succeeding samples of a simple exponential (or envelope of a damped sinusoid) differ at most by a factor of R^{-1}. When these two restrictions are combined, the poles must lie in the region defined by Eq. 3.29

$$-\phi \leq \arg z \leq \phi \; ; \quad 1 \leq |z| < R \tag{3.29}$$

The corresponding restriction on the pole positions of the Laplace transform of the continuous time function in the s-plane is

$$-\frac{\phi}{\tau} \leq \omega \leq \frac{\phi}{\tau} \; ; \quad -\frac{1}{\tau} \log R < \sigma \leq 0 \tag{3.30}$$

Thus the poles in the s-plane must lie in the principal-value strip centered about the origin in Fig. 3.7. It is conceivable that if the poles were located in other horizontal strips, the conditions of Eq. 3.29 could still be satisfied (refer to Fig. 3.9). This possibility can be excluded since, if τ were decreased, the angle of the pole positions would increase to a value greater than ϕ. This difficulty can be resolved by adding another condition to the criterion, namely, the poles must remain in the region defined by Eq. 3.29 for all smaller values of τ. This condition is equivalent to confining the poles of the transform of the continuous time function to the principal-value strip in the s-plane. A reasonable practical determination for τ_{max} is obtained by letting $\phi = \pi/2$ and $R = 1.5$. This allows at least four sample values per cycle for each sinusoid and maximum variation of about forty percent between successive samples of each real exponential.

If the z-transform method is to be useful as an analysis or synthesis technique, the time series operations discussed in connection with band-limited functions must still be applicable. In particular, does the product of two

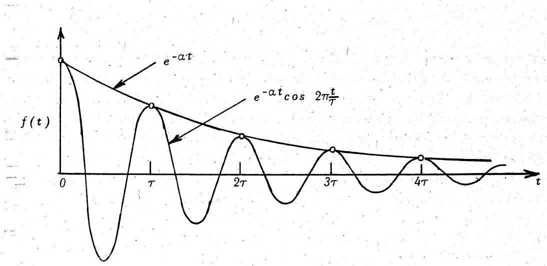

FIG. 3.8.--Two time functions having the same z-transform.

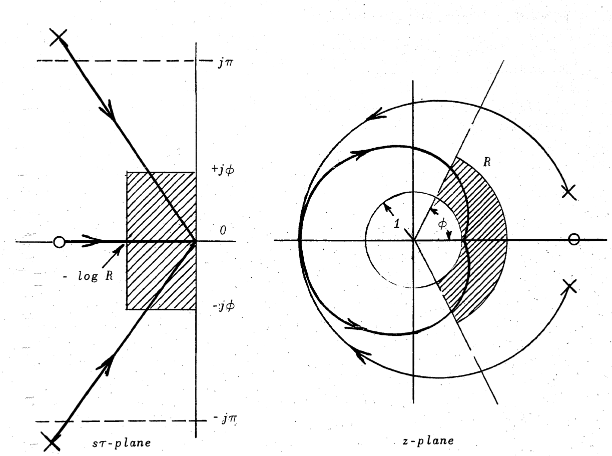

FIG. 3.9.--Pole-zero loci for decreasing τ.

z-transforms yield the z-transform of the convolution of the two corresponding time functions? The answer is that this representation is only approximate since, unlike the time series representation for band-limited functions, the impulse series is an approximation to the actual time function. To illustrate the difference between the sample values for $F^*(z)G^*(z)$ and $FG^*(z)$, the simple example of convolution of a step function with the impulse response of an RC filter is demonstrated in Fig. 3.10 for various values of sampling interval. Note that the approximation, $F^*(z)G^*(z)$, improves as the sampling interval is decreased.

The Laplace transform of the output voltage is

$$F(s)G(s) = \frac{a}{s(s+a)} = \frac{1}{s} - \frac{1}{s+a} \tag{3.31}$$

From Table I, the exact z-transform is

$$FG^*(z) = \frac{-1}{z-1} + \frac{e^{a\tau}}{z-e^{a\tau}} = \frac{(e^{a\tau}-1)\,z}{(z-1)(z-e^{a\tau})} \tag{3.32}$$

Convolution of two impulses of area a_1 and b_1 over the interval τ yields a sample value of $\tau a_1 b_1$; hence the approximate z-transform of the output is given by

$$\tau F^*(z)\,G^*(z) = \left(\frac{-1}{z-1}\right)\left(\frac{-a\tau e^{a\tau}}{z-e^{a\tau}}\right) \tag{3.33}$$

$$= \frac{\dfrac{-a\tau e^{a\tau}}{e^{a\tau}-1}}{z-1} + \frac{\dfrac{a\tau e^{a\tau}}{e^{a\tau}-1}}{z-e^{a\tau}} \tag{3.34}$$

The disturbingly large errors for apparently reasonable values of τ suggest that for convolution purposes, approximation by an impulse sequence is not sufficiently close. Fortunately, a slight modification of the method can be made to yield very good results without decreasing the sampling interval. In order to develop this method it must first be shown that convolution of a continuous time function with an impulse sequence can be represented exactly in terms of sample values simply by multiplication of their respective z-transforms.

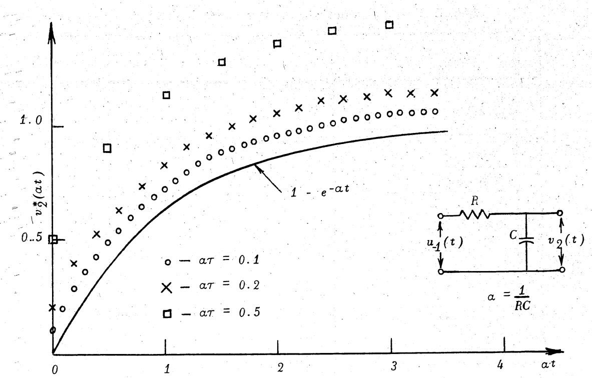

FIG. 3.10.--Convolution by multiplication of z-transforms.

Let

$$\mathcal{L}[f(t)] = F(s) \text{ (rational)} \tag{3.35}$$

$$g(t) = \sum_{k=0}^{\infty} a_k\, u_0(t - k\tau) \tag{3.36}$$

$$G(z) = \sum_{k=0}^{\infty} a_k\, z^k \tag{3.37}$$

$$h(t) = f(t) * g(t) \tag{3.38}$$

Performing the indicated convolution, we have

TABLE I.---z-transforms for typical time functions.

	$f(t)$ $(t > 0)$	$F(s)$	$F^*(z)$
1	$u_o(t)$	1	1
2	$u_o(t - k\tau)$ (k integer)	$e^{-ks\tau}$	z^k
3	$u_{-1}(t)$	$\frac{1}{s}$	$\frac{-1}{z - 1}$
4	t	$\frac{1}{s^2}$	$\frac{\tau z}{(z - 1)^2}$
5	$\frac{t^2}{2}$	$\frac{1}{s^3}$	$-\frac{\tau^2 z(z + 1)}{2(z - 1)^3}$
6	$\frac{t^3}{6}$	$\frac{1}{s^4}$	$\frac{\tau^3 z(z^2 + 4z + 1)}{6(z - 1)^4}$
7	$\frac{t^4}{24}$	$\frac{1}{s^5}$	$-\frac{\tau^4 z(z^3 + 11z^2 + 11z + 1)}{24(z - 1)^5}$
8	$e^{-\alpha t}$	$\frac{1}{s + \alpha}$	$\frac{-e^{\alpha\tau}}{z - e^{\alpha\tau}}$
9	$\sin \beta t$	$\frac{\beta}{s^2 + \beta^2}$	$\frac{z \sin \beta\tau}{z^2 - (2 \cos \beta\tau)z + 1}$
10	$e^{-\alpha t} \sin \beta t$	$\frac{\beta}{(s + \alpha)^2 + \beta^2}$	$\frac{z e^{\alpha\tau} \sin \beta\tau}{z^2 - (2 \cos \beta\tau)z + e^{2\alpha\tau}}$
11	$\cos \beta t$	$\frac{s}{s^2 + \beta^2}$	$\frac{1 - z \cos \beta\tau}{z^2 - (2 \cos \beta\tau)z + 1}$
12	$e^{-\alpha t} \cos \beta t$	$\frac{s + \alpha}{(s + \alpha)^2 + \beta^2}$	$\frac{e^{\alpha\tau}(e^{\alpha\tau} - z \cos \beta\tau)}{z^2 - (2e^{\alpha\tau} \cos \beta\tau)z + e^{2\alpha\tau}}$
13	$1 - e^{-\alpha t}$	$\frac{\alpha}{s(s + \alpha)}$	$\frac{(e^{\alpha\tau} - 1) z}{(z - 1)(z - e^{\alpha\tau})}$

TABLE I.--(Cont'd)

	$f(t)$ $(t > 0)$	$F(s)$	$F^*(z)$
14	$\sum_{k=0} a_k e^{s_k t}$	$\sum_k \frac{a_k}{s - s_k}$	$\sum_k \frac{-a_k e^{-s_k\tau}}{z - e^{-s_k\tau}}$
15	$te^{-\alpha t}$	$\frac{1}{(s + \alpha)^2}$	$\frac{\tau e^{\alpha\tau} z}{(z - e^{\alpha\tau})^2}$
16	$\frac{t^2}{2} e^{-\alpha t}$	$\frac{1}{(s + \alpha)^3}$	$-\frac{\tau^2 e^{\alpha\tau} z(z + e^{\alpha\tau})}{2(z - e^{\alpha\tau})^3}$
17	$\frac{t^3}{6} e^{-\alpha t}$	$\frac{1}{(s + \alpha)^4}$	$\frac{\tau^3 e^{\alpha\tau} z(z^2 + 4e^{\alpha\tau} z + e^{2\alpha\tau})}{6(z - e^{\alpha\tau})^4}$
18	$u_{-1}(t) - u_{-1}(t - k\tau)$ (rectangular pulse)	$\frac{1 - e^{-sk\tau}}{s}$	$\frac{z^k - 1}{z - 1}$
19	$-a^{-(t/\tau + 1)}$	$\frac{-\frac{1}{a}}{s + \frac{1}{\tau} \log a}$	$\frac{1}{(z - a)}$
20	$\left(1 + \frac{t}{\tau}\right) a^{-(t/\tau + 2)}$	$\frac{\frac{1}{\tau a^2}}{(s + \frac{1}{\tau} \log a)^2} + \frac{\frac{1}{a^2}}{(s + \frac{1}{\tau} \log a)}$	$\frac{1}{(z - a)^2}$
21	$-\left(1 + \frac{3t}{2\tau} + \frac{t^2}{2\tau^2}\right) a^{-(t/\tau + 3)}$	$\frac{-\frac{1}{\tau^2 a^3}}{(s + \frac{1}{\tau} \log a)^3} - \frac{\frac{3}{2\tau a^3}}{(s + \frac{1}{\tau} \log a)^2} - \frac{\frac{1}{a^3}}{s + \frac{1}{\tau} \log a}$	$\frac{1}{(z - a)^3}$
22	$f(t - k\tau)$	$e^{-sk\tau} F(s)$	$z^k F^*(z)$
23	$[f(t)][\sum_k a_k u_o(t - k\tau)]$	$F(s) \sum_k a_k e^{-sk\tau}$	$F^*(z) \sum_k a_k z^k$
24	$e^{-\alpha t} f(t)$	$F(s + \alpha)$	$F^*(e^{-\alpha\tau} z)$
25	$\lim_{t \to 0} f(t)$	$\lim_{s \to \infty} sF(s)$	$\lim_{z \to 0} F^*(z)$
26	$\lim_{t \to \infty} f(t)$	$\lim_{s \to 0} sF(s)$	$\lim_{z \to 1} (1 - z) F^*(z)$

$$h(t) = \sum_{k=0}^{\infty} a_k \, f(t - k\tau) \tag{3.39}$$

$$H^*(z) = \sum_{k=0}^{\infty} a_k \, z^k \, F^*(z) \tag{3.40}$$

Then

$$H^*(z) = F^*(z)\; G(z) \tag{3.41}$$

Time functions and z-transforms in the form of Eqs. 3.36 and 3.37 have considerable practical significance in the analysis of line-lumped networks as will be pointed out later. The impulse response of a purely distributed-element network must be of the form of Eq. 3.36.

Returning to the problem of obtaining a better approximation to the continuous time function, an obvious improvement is to replace each impulse in $f^*(t)$ by a rectangular pulse with height equal to the sample value and duration equal to the sampling interval. This results in the staircase approximation of Fig. 3.11. An even better approximation is obtained by replacing the impulses with triangular pulses of duration 2τ. The convolution operation can best be visualized by the aid of block diagrams and transfer functions. The operation of replacing the impuses by finite pulses can be represented by the linear filters of Fig. 3.12. These filters are called low-pass interpolation filters. The fact that an output before $t = 0$ may be required is immaterial since the filters represent only mathematical operations. The operation of taking the z-transform of a time function is represented symbolically by some authors simply as a sampling switch. Linvill[1] prefers the use of an impulse modulator having the properties shown in Fig. 3.13. Sampling is a non-linear operation and as such cannot be represented by a transfer function. The convolution performed in Eq. 3.33 has the block diagram representation of Fig. 3.14. The improved method of convolution is shown in Fig. 3.15. The interpolation filter converts the sampled signal from $F(s)$ into a signal more nearly like $f(t)$ at the input to $G(s)$. The combined transfer function of the interpolation filter and $G(s)$ is the product of a function rational in s and a function rational in z, $[J(s)G(s)]\,[K(z)]$,

[1]W. K. Linvill *''Use of sampled functions for time domain synthesis,''* Proc. National Electronics Conference, Vol. 9., September 1953, pp. 533-542.

hence the z-transform of the combination is obtained by multiplication as indicated in Eq. 3.41. To illustrate the application of this method, consider the convolution problem of Fig. 3.10. If a rectangular pulse interpolation filter[1] is used (Fig. 3.16), the combined transfer function between impulse modulators is given by

$$J(s)\; G(s)\; K\,(z) = \frac{a}{s(s + a)}\;(1 - z) \tag{3.42}$$

The corresponding z-transform is

$$\frac{(e^{a\tau} - 1)\; z}{(z - 1)(z - e^{a\tau})} \cdot (1 - z) \tag{3.43}$$

Now combining this with the z-transform of the unit step, we get the approximate z-transform of the output

$$\left(\frac{-1}{z - 1}\right)\left(\frac{(e^{a\tau} - 1)\; z}{(z - 1)(z - e^{a\tau})}\right)(1 - z) = \frac{(e^{a\tau} - 1)\; z}{(z - 1)(z - e^{a\tau})} \tag{3.44}$$

By comparison with Eq. 3.32 it is noticed that the exact z-transform resulted in this case. Fortunately, the rectangular pulse interpolation filter was a good choice for this example. Notice that this particular interpolation filter converted the sampled step function back to its original shape, thus making the input to the RC filter exact. This behavior, of course, will not happen in general and usually the triangular interpolation will give better results. To recapitulate, the analytical use of interpolation filters to obtain better approximations to the time functions has greatly improved the accuracy of the convolution process without the necessity of decreasing the sampling interval and has retained the utility of the z-transform as an analysis method.

The application of z-transform techniques to the problem of finding the time response of line-lumped networks is very similar to the analysis of mixed sampled-data and continuous systems. The delay operators of the form $e^{-ks\tau}$

[1]Called a ''holding circuit'' in servomechanism theory.

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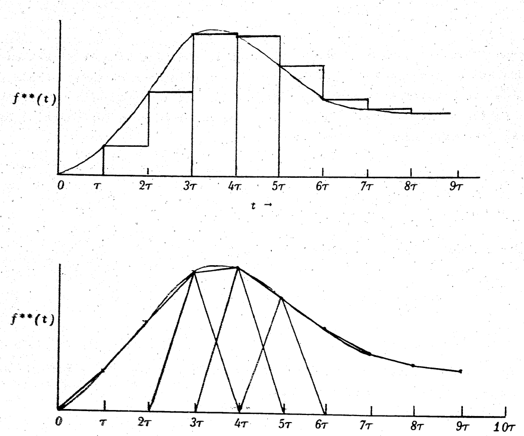
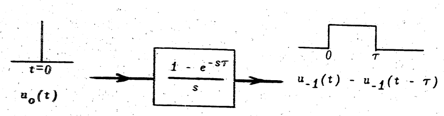
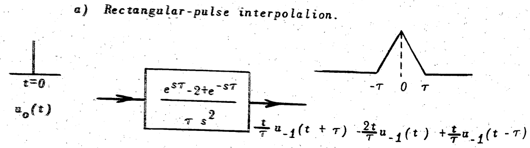


FIG. 3.11.--Staircase and polygonal approximations to $f(t)$.



Transfer function $= \frac{1}{s}\ (1 - z)$

a) Rectangular-pulse interpolation.



Transfer function $= \frac{1}{\tau s^2}\ \frac{(z - 1)^2}{z}$

b) Triangular-pulse interpolation.

FIG. 3.12.--Low-pass interpolation filters.

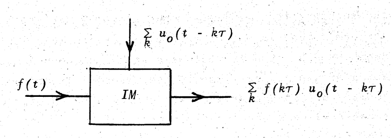


FIG. 3.13.--Impulse modulator.

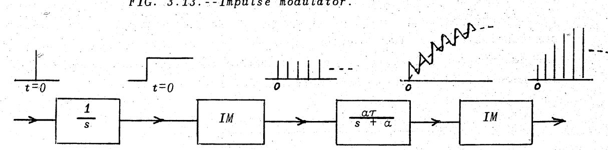


FIG. 3.14.--Symbolic representation of convolution problem of Fig. 3.10.

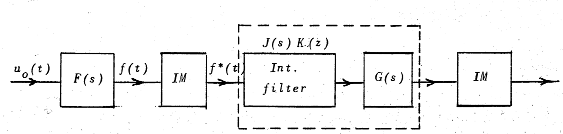


FIG. 3.15.--Improved convolution method.

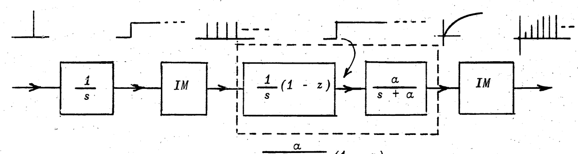


FIG. 3.16.--Example with staircase approximation.

in the transfer functions of line-lumped networks transform simply to z^k. The z-transform method is not characterized by the inability to reproduce discontinuous or echo type or responses at times removed from the time origin. Consideration of the general form of the transfer function (Eq. 3.01) reveals that the numerator and denominator are composed of the sum of products of functions rational in s and functions rational in z. Hence the z-transform of the numerator and denominator can be found simply by application of Eq. 3.41 and the use of an interpolation filter. Inversion by expanding the resulting ratio of polynomials in z in a power series in z is equivalent to the inverse convolution of two time functions whose Laplace transforms are the numerator and denominator respectively of the transfer function. The example of Eq. 3.45 is shown using triangular interpolation filters.

$$Y(s) = \frac{A_o(s) + A_1(s)\, e^{-sT_1} + A_3(s)\, e^{-sT_3}}{B_o(s) + B_2(s)\, e^{-sT_2} + B_4(s)\, e^{-sT_4}} \tag{3.45}$$

$$Y^*(z) \simeq \frac{A_o^*(z) + A_1^*(z)\, z^{k_1} + A_3^*(z)\, z^{k_3}}{\frac{(z-1)^2}{z} C_o^*(z) + z^{k_2-1}(z-1)^2 C_2^*(z) + z^{k_4-1}(z-1)^2 C_4^*(z)} \tag{3.46}$$

where

$$C_{2n}(s) = \frac{B_{2n}(s)}{\tau s^2}; \; k_1,\ k_2 \text{ - - - } k_4 \text{ are integers}$$

$$Y^*(z) \simeq \frac{g_o + g_1 z + g_2 z^2 + \text{ - - - } + g_p z^p}{h_o + h_1 z + h_2 z^2 + \text{ - - - } + h_q z^q} \tag{3.47}$$

For this analysis it is required that all delay lines in the network be of commensurate length so that each T will be an integral multiple of the sampling interval, τ. This requirement will not be a serious practical limitation. The inversion of the z-transform of Eq. 3.47 will normally be accomplished by long division but in the simpler cases a partial-fraction expansion could be used. The following examples will illustrate the method.

Example 1: The sample values of the rectangular pulse, $p(t)$, used for an example in Section B, are easily obtained from a series expansion of $P^*(z)$. No interpolation is necessary.

$$P(s) = \frac{1 - e^{-sT}}{s} \tag{3.10}$$

Let

$$\tau = \frac{T}{5},$$

$$P^*(z) = \frac{1 - z^5}{1 - z} = 1 + z + z^2 + z^3 + z^4$$

Example 2: The network example of Fig. 3.1. in Section III-A will be used to illustrate the procedure for finding the approximate sample values.

From Eq. 3.05,

$$V_2(s) = \frac{\frac{4}{3}\left[\frac{1}{s(s+1)}\right] e^{-s}}{\left[1 - \frac{1}{3}\left(\frac{s-1}{s+1}\right) e^{-2s}\right]} = \frac{A(s)}{B(s)}$$

Now using only rectangular-pulse interpolation as shown in Fig. 3.12a, we let

$$V_2^*(z) \cong \frac{A^*(z)}{C^*(z)\,[1 - z]}$$

where

$$C(s) = \frac{B(s)}{s}$$

$$A(s) = \frac{4}{3}\left[\frac{1}{s} - \frac{1}{s+1}\right] e^{-s}$$

$$A^*(z) = \frac{4}{3}\left[\frac{1}{1 - z} - \frac{1}{1 - e^{-\tau}z}\right]z^{1/\tau}$$

Choose $\tau = 0.5$ seconds, then

$$A^*(z) = \frac{4}{3}\left[\frac{0.393z^3}{(1 - z)(1 - 0.607z)}\right]$$

$$C(s) = \frac{1}{s} - \frac{1}{3}\left[\frac{s - 1}{s(s + 1)}\right]e^{-2s}$$

$$C^*(z) = \frac{1}{1 - z} - \frac{1}{3}\left[\frac{-1}{1 - z} + \frac{2}{1 - 0.607z}\right]z^4$$

$$= \frac{3 - 1.82z - z^4 + 1.393z^5}{3(1 - z)(1 - 0.607z)}$$

$$V_2^*(z) \cong \frac{A^*(z)}{C^*(z)[1 - z]} = \frac{1.57z^3}{(3 - 1.82z - z^4 + 1.393z^5)(1 - z)}$$

$$V_2^*(z) \cong \frac{1.57z^3}{3 - 4.82z + 1.82z^2 - z^4 + 2.393z^5 - 1.393z^6}$$

The approximate sample values of $v_2(t)^*$ are coefficients of the power series in z obtained simply by long division.

$$V_2^*(z) \cong 0.524z^3 + 0.842z^4 + 1.032z^5 + 1.150z^6 + 1.396z^7$$
$$+ 1.410z^8 + 1.338z^9 + 1.242z^{10} + 1.212z^{11} + 1.087z^{12} + 0.980z^{13}$$
$$+ 0.917z^{14} + 0.914z^{15} + 0.880z^{16} + 0.884z^{17} + 0.917z^{18} + 0.965z^{19}$$
$$+ 0.983z^{20} + 1.010z^{21} + 1.040z^{22} + 1.057z^{23} + 1.017z^{24} + - - -$$
$$+ - - - - - - -$$

These sample values are plotted on the graph of Fig. 3.1b for comparison with the actual time function.

A few concluding comments on the time-series method of analysis may be appropriate. If the time response of a line-lumped network should contain impulses, an ambiguity arises in that the z-transform cannot distinguish between an impulse and a finite sample value. It is usually a simple matter to determine the existence of impulsive responses by other means so that the ambiguity may be resolved.

The time-series is a useful representation for numerical data such as the impulse response or driving function of a filter. This will be discussed later in connection with the problem of synthesis of a prescribed transient response. Huggins[1] has pointed out that a large error in the sample values may result when the division process is carried out if there exists even a small error in the initial sample values of the numerator and denominator. He suggests a new variable, λ, related linearly to z but having its origin correspond to a value of s different from infinity. This reduces the effect of high-frequency ''noise'' disturbing the initial sample values.

An essentially different approach to the determination of the z-transform is presented by Boxer and Thaler[2]. The transformation $s = 1/\tau \ln z$ is approximated by a rational function in z. By substitution of this function in the Laplace transform for s, an approximate z-transform is obtained. The inversion is carried out by the long division process.

[1] W. H. Huggins, ''*A low-pass transformation for z-transforms,*'' IRE Trans., Vol. CT-1, September 1954, Correspondence p. 69.

[2] R. Boxer and S. Thaler, ''*A simplified method of solving linear and non-linear systems,*'' Proc. IRE, Vol. 44, January 1956, pp. 89-101.

IV. RESPONSE CHARACTERISTICS OF LINE-LUMPED NETWORKS

The purpose of this chapter is to discuss those properties of frequency-domain and time-domain response of line-lumped networks which are significantly different from the response characteristics of purely lumped-element networks. Some of these differences were mentioned in Chapter III. It is from a knowledge of these special response properties that we hope to be able to develop some useful synthesis techniques.

A large part of the network theory developed for lumped-element networks is sufficiently general to include the idealized distributed element. In particular, those arguments based upon energy considerations apply equally well to line-lumped networks. For instance, the driving-point immittance of a passive line-lumped network must be positive-real, therefore it has no zeros or poles in the right half of the s-plane. A reactance function, $X(s)$, has all zeros and poles on the ω-axis, obeying the separation property and $dX/d\omega \geq 0$ for all ω. Any stable line-lumped network must have no natural frequencies in the right-half plane.

The important results of this chapter are presented as theorems in order to emphasize the facts which are essential to an understanding of the behavior of line-lumped networks.

A. FREQUENCY-DOMAIN PROPERTIES

In this chapter it will be assumed that the delay-line lengths are commensurable, i.e., there exists some time interval, τ, which is a common submultiple of the time delay of all elements of the network. This restriction imposes no practical difficulty and simplifies the analysis.

Theorem 1: *The transfer function of a network containing only delay lines and resistors is periodic on any path, σ = constant, in the s-plane.* This relation follows from the fact that the transfer function is rational in $e^{-s\tau}$, and hence in z. The locations of the poles and zeros in the s-plane can be found by locating the poles and zeros in the z-plane, since each horizontal strip of width $2\pi/\tau$ in the s-plane maps into the entire z-plane. The resulting pole-zero pattern consists of vertical ''strings'' of equally spaced poles and zeros in the s-plane. This property of periodic frequency response will be useful for synthesis, as demonstrated in Chapter V.

The general form for the transfer function of a line-lumped network was given in Eq. 3.01. By multiplying the numerator and denominator by polynomials in s, this expression can be put in the form of Eq. 4.01.

$$F(s) = \frac{P_{no}(s) + P_{n1}(s)\, e^{-s\tau} + P_{n2}(s)\, e^{-2s\tau} + \cdots P_{n\mu} e^{-\mu s\tau}}{P_{do}(s) + P_{d1}(s)\, e^{-s\tau} + \cdots P_{d\nu} e^{-\nu s\tau}} \qquad (4.01)$$

Where the $P_{nk}(s)$ and $P_{dk}(s)$ are polynomials in s. $F(s)$ is a meromorphic function and as such its only singularities in the finite part of the s-plane are isolated poles. In the form of Eq. 4.01, the poles are given only by the zeros of the denominator. In order to find the nature of the pole-zero locations of the transfer function, we should investigate the zero positions of a function of the form of Eq. 4.02 since the numerator and denominator of the transfer function are of this same form.

$$R(s) = \sum_{k=0}^{n} P_k(s)\, e^{-ks\tau} \qquad (4.02)$$

where $P_k(s)$ are polynomials in s, and n is the highest power of $e^{-s\tau}$. $R(s)$ could equally well be written:

$$R(s) = \sum_{j=0}^{m} Q_j(e^{-s\tau})\, s^j \qquad (4.03)$$

where the $Q_j(e^{-s\tau})$ are polynomials in $e^{-s\tau}$ and m is the degree of the $P_k(s)$ of highest degree.

The process of solving for the zeros of $R(s)$ directly is a hopelessly tedious task; however some important general statements can be made. In function theory, $R(s)$ is classified as an integral function of order one; it might be considered the simplest class of integral functions except for the polynomial, which is of order zero. For a further study of the properties of these functions, the texts of Titchmarsh[1] and Copson[2] are excellent references.

From physical reasoning we should expect that the pole-zero locations should tend to become periodic in ω as s is made very large. For some

[1] E. C. Titchmarsh, *The Theory of Functions,* Oxford Press, 1932, Ch. III, and Ch. VIII.

[2] E. T. Copson, *An Introduction to the Theory of Functions of a Complex Variable,* Oxford Press, 1935, Ch. VII.

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sufficiently large s, all capacitors in the network approach short-circuits and all inductors approach open-circuits, so that at high frequencies the network is essentially a delay line and resistor network. From theorem 1, the poles and zeros lie equally spaced on vertical lines in the s-plane. In fact, from Eq. 4.03 we can find periodic sets of zeros which are approached asymptotically by the zeros of $R(s)$ as s becomes large.

Theorem 2: *The zeros of $R(s)$ approach the zeros of $Q_m(e^{-s\tau})$ as* $s \to \infty$.

$$R(s) = s^m \left\{ Q_m(e^{-s\tau}) + \left[\frac{Q_{m-1}}{s} + \frac{Q_{m-2}}{s^2} + \cdots + \frac{Q_o}{s^m}\right] \right\}$$

For any finite σ, the Q_j are bounded; as $s \to \infty$ for finite σ, the term

$$\sum_{j=0}^{m-1} \frac{Q_j}{s^{m-j}}$$

becomes arbitrarily small compared to Q_m. Hence the roots of the predominant term, Q_m, determine the roots of $R(s)$ in this region.

Theorem 3: *The number of zeros in any infinite horizontal strip of finite width is finite.* Refering to Fig. 4.1, region I, inside the rectangle bounded by σ_1, σ_2, ω_1, and ω_2 must, of course, have only a finite number of zeros since the region is of finite extent. (Since the zeros are isolated, a finite region contains a finite number of zeros.) In region II, the term

$$\sum_{k=1}^{n} P_k(s)\, e^{-ks\tau}$$

can be made arbitrarily small compared to $P_o(s)$ by choosing σ_1 sufficiently large; the zeros in this region approach the zeros of P_o.

$$R(s) = P_o(s) + \{P_1(s)\, e^{-s\tau} + P_2(s)\, e^{-2s\tau} + \cdots P_n(s)\, e^{-ns\tau}\}$$

$$\longrightarrow P_o(s) \quad as\ \sigma \to \infty$$

Similarly, in region III,

$$R(s) = e^{-ns\tau}\, \{P_n(s) + [P_{n-1}(s)\, e^{s\tau} + \cdots + P_o(s)\, e^{ns\tau}]\}$$

For $|\sigma_2|$ sufficiently large in the LHP,

$$R(s) \to e^{-ns\tau}\, P_n(s)$$

By these arguments, theorem 3 is proven.[1]

The network examples of Fig. 4.2 illustrate the nature of the pole-zero pattern in the s-plane for simple impedance functions.

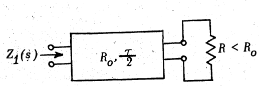
FIG. 4.1.--Typical s-plane region used in the proof of Theorem 3.

[1]It can also be shown, by an extension of Jensen's theorem, that since $R(s)$ is of order one, the series

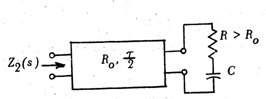
$$\sum_{n=1}^{\infty} r_n^{-(1+\epsilon)}$$

will converge for ϵ arbitrarily small. r_n are the moduli of the zeros. This implies that $n(r) < k\, r^{(1+\epsilon)}$; $n(r)$ is the number of zeros in a circle of radius r, and k is independent of r.

See Titchmarsh, op. cit. p. 249.



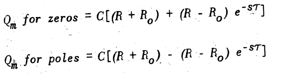
$$Z_1(s) = R_o \frac{(R_o + R) - (R_o - R)\, e^{-sT}}{(R_o + R) + (R_o - R)\, e^{-sT}}$$



$$Z_2(s) = R_o \frac{1 + (R + R_o)\, Cs + [1 + (R - R_o)\, Cs]\, e^{-sT}}{1 + (R + R_o)\, Cs - [1 + (R - R_o)\, Cs]\, e^{-sT}}$$

Q_m *for zeros* $= C[(R + R_o) + (R - R_o)\, e^{-sT}]$

Q_m *for poles* $= C[(R + R_o) - (R - R_o)\, e^{-sT}]$



$$Z_3(s) = R_o \frac{R + R_o + RR_oCs + [R - R_o - R_oRCs]\, e^{-sT}}{R + R_o + RR_oCs - [R - R_o - R_oRCs]\, e^{-sT}}$$

Q_m *for zeros* $= RR_oC(1 - e^{-sT})$

Q_m *for poles* $= RR_oC(1 + e^{-sT})$

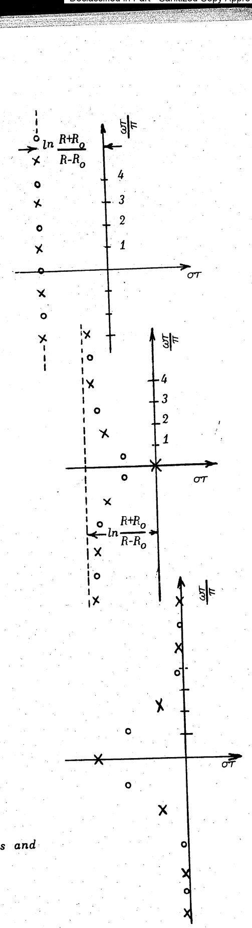


FIG. 4.2.--Some impedance functions and pole-zero patterns.

B. TRANSIENT RESPONSE CHARACTERISTICS

The impulse response of a lumped-element network must have a rational Laplace transform. The general form of this type of time function is the sum of products of polynomials and exponentials in t for $t > 0$, hence the impulse response and all its derivatives must be continuous for all $t > 0$. The following discussion will point out some striking differences between the impulse response of line-lumped networks and the impulse response of lumped-element networks. These differences will be used to advantage in Chapter V in the development of new approaches to the time-domain synthesis problem.

Theorem 4: *The impulse response of a network containing only delay lines and resistors is an impulse sequence,*

$$f(t) = \sum_{k=0}^{\infty} f_k \, u_o(t - T_k)$$

in $t \geq 0$. This relation is intuitively obvious from the fact that the traveling waves on the delay lines must be impulses. It also follows directly from Theorem 1 since the spectrum of the impulse response is periodic. If the transfer function has no poles in the finite part of the s-plane, the impulse sequence is finite since the transfer function would be a polynomial in e^{-sT}.

From series expansion of the transfer function of a line-lumped network shown in Eq. 3.04, the nature of the impulse response can be determined. Theorem 5: *The impulse response of a line-lumped network having delay parameters,* $T_1, T_2, \text{- - -} T_n$, *consists of segments of time functions having rational Laplace transforms between definite break times,* t_k. *The* t_k *are given by*

$$t_k = \sum_{j=1}^{n} a_{kj} \, T_j \tag{4.04}$$

The a_{kj} *assume all positive integral values including zero. At the* t_k, *the impulse response or its derivatives may be discontinuous.*[1] This discontinuous behavior of the impulse response is the outstanding feature of networks containing delay-line elements. It is possible to construct a

[1] In fact, the integral of the impulse response may be discontinuous at any or all t_k.

line-lumped network whose impulse response is non-zero only over a finite time interval. This particular form of impulse response will be called a ''pulse-function'' and will receive considerable attention in the synthesis procedures of Chapter V. For our purposes we will define the pulse function, $p(t)$, more specifically as a time function bounded in the interval,

$$T_a \leq t \leq T_b$$

where $T_a \geq 0$, and being identically zero outside this interval.[2]

It will be interesting to study the properties of the transfer function, $P(s)$, of a network whose impulse response is a pulse function.

Theorem 6: *A necessary condition that $P(s)$ be the Laplace transform of a pulse function is that $P(s)$ have no poles in the finite part of the s-plane and that the number of zeros in the entire s-plane be infinite.* The Laplace transform of $P(s)$ is given by

$$P(s) = \int_0^\infty p(t)\, e^{-st}\, dt = \int_{T_a}^{T_b} p(t)\, e^{-st}\, dt \tag{4.05}$$

Since the limits of integration in Eq. 4.05 are finite, the expression must converge to a finite value for all finite values of s. If, however, $P(s)$ has a finite number of zeros, it is a polynomial. The inverse transform of a polynomial in s is the sum of an impulse and its derivatives at $t = 0$ and hence does not satisfy the definition of a pulse function.

Theorem 7: *A sufficient condition that $P(s)$ be the Laplace transform of a pulse function is that*

$$P(s) = G(s)\, F(e^{-s\tau}) \tag{4.06}$$

where $G(s)$ is rational in s and $F(e^{-s\tau})$ is a polynomial in $e^{-s\tau}$ such that all the poles of $G(s)$ are exactly cancelled by zeros of $F(e^{-s\tau})$. The condition that $p(t)$ be bounded requires that the number of zeros of $G(s)$ be less than the number of poles. The zero pattern of $P(s)$ is obtained directly

[2] It is worth noting that networks with pulse-function impulse response are characterized by step responses tangent to the final value, rather than asymptotic to the final value as in the case of lumped-element networks.

from the vertical ''strings'' of periodically spaced zeros generated by $F(e^{-s\tau})$ except that a finite number of these zeros are cancelled by the poles of $G(s)$ and in addition there are the arbitrarily placed zeros of $G(s)$. The zero patterns for the transforms of particular pulse functions are shown in Fig. 4.3.

The proof of Theorem 7 follows from an investigation of the integrand of the inversion integral for $p(t)$ for different values of t.

$$p(t) = \frac{1}{2\pi j} \oint_{B_r} P(s)\, e^{st} ds = \frac{1}{2\pi j} \oint_{B_r} G(s)\left[\sum_{k=0}^{n} f_k e^{-ks\tau}\right] e^{st} ds \tag{4.07}$$

The path of integration is the usual Bromwich path which encloses the LHP in an infinitely large semi-circle. By definition, the integrand, $P(s)\, e^{st}$, has no poles in the finite part of the s-plane and from Eq. 4.08 for $t > n\tau$, $P(s)\, e^{st} \to 0$ as $s \to \infty$ in the LHP.

$$P(s)\, e^{st} = G(s)\, [f_o e^{st} + f_1 e^{s(t-\tau)} + f_2 e^{s(t-2\tau)} + \cdots f_n e^{s(t-n\tau)}] \tag{4.08}$$

Thus the integral in Eq. 4.07 vanishes for all $t > n\tau$.

Note that convolution of a pulse function with another pulse function or with a finite impulse sequence yields a pulse function. For this reason, the superposition of relatively simple zero patterns like those of Fig. 4.3 will give the zero pattern for a very complex pulse function. Also, the sum of pulse functions is a pulse function but the corresponding zero pattern is not necessarily of the form of partially cancelled vertical strings of zeros.

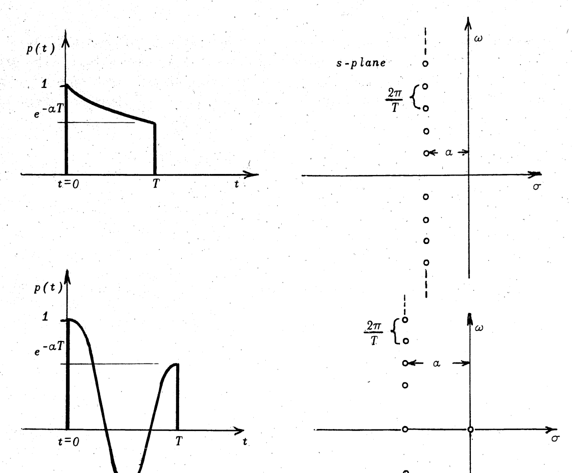


FIG. 4.3.--Some pulse functions and zero patterns of their transforms.

V. NETWORK SYNTHESIS

The response properties of line-lumped networks discussed in Chapter IV suggest some new approaches to network synthesis. Synthesis procedures having a lumped-element network realization make a sharp distinction between the approximation problem and the realization problem. In this case, the prescribed response must be approximated by a limited class of functions. The prescribed frequency response must be approximated by functions rational in $j\omega$; the prescribed impulse response must be approximated by time functions having rational Laplace transforms, thus having the form,[1]

$$\sum_m \sum_n a_{mn} \; t^m e^{s_n T} \; , \quad (t > 0)$$

The response of line-lumped networks is not nearly so restricted, and although approximation and realization are still separate problems, the realization procedures are very closely linked to the various types of approximation procedures discussed in this chapter.

The general form of the transfer function for a line-lumped network, represented by Eq. 3.01, is considered too complicated to be useful for synthesis. Although realization procedures might be found for this general form, the approximation problem would be very difficult and of questionable value. Special forms of the transfer function, however; are applicable to synthesis and furthermore have response characteristics radically different from those of rational transfer functions. One such specialization which exhibits many interesting possibilities is a transfer function composed of the product of a function rational in s and a function rational in z.

$$H(s,z) = G(s)\,F(z) \tag{5.01}$$

The cascading of networks is considered in the operational sense in this chapter, i.e., the transfer function of a cascade of networks is equal to the product of the individual transfer functions. Presumably unilateral elements would be available for the actual network realization which could serve as isolating devices.

A. TAPPED DELAY-LINE FILTER AND INTERPOLATION FILTER

The time-series representation for a function as discussed in Chapter III

[1]These are necessary conditions; not sufficient.

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would appear to be a very useful approximating function for a prescribed impulse response. Fortunately, a very straightforward line-lumped network realization for a time-series type of impulse response exists. This realization is a tapped-delay-line (TDL) filter used in conjunction with some sort of interpolation filter. Referring to the circuit arrangement of Fig. 5.1, the delay line is tapped at delay intervals equal to the sampling interval of the time series. The line is terminated and tapped in such manner as to make all reflections of negligible amplitude. The tap outputs, after being individually adjusted to some prescribed level, are added together to form the output of the filter. Note that the impulse response for the TDL filter is an impulse sequence for which the area of the *kth* impulse can be arbitrarily set at f_k (positive or negative). The f_k*'s* are called the tap factors.

$$f(t) = \sum_{k=0}^{N} f_k\, u_o(t - k\tau) \tag{5.02}$$

If the impulse response of the low-pass interpolation filter is $g(t)$, the impulse response of the cascade combination of both filters will be given by

$$h(t) = \sum_{k=0}^{N} f_k\, g(t - k\tau) \tag{5.03}$$

Suppose that the interpolation filter is an ideal low-pass filter, then the impulse response of the combined network is that given by Eq. 3.16.

$$h(t) = \sum_{k=0}^{N} f_k \frac{\sin \frac{\pi}{\tau}(t - k\tau)}{\frac{\pi}{\tau}(t - k\tau)} \tag{3.16}$$

This is a continuous, band-limited time function which passes through the prescribed sample values, f_k, as determined by setting of the individual tap factors.

This type of time-domain synthesis has several advantages over conventional lumped-element network synthesis. First of all, it is readily applicable to numerically prescribed impulse response data; the approximation problem involves only the choice of a suitable interpolating function, $g(t)$. Secondly, an obvious advantage is that once a TDL-interpolation filter has been built it can be used repeatedly for many different prescribed impulse responses provided that the tap factors are made adjustable by means of potentiometers or other variable gain elements. Thirdly, the ease of

FIG. 5.1.--TDL filter and interpolation filter.

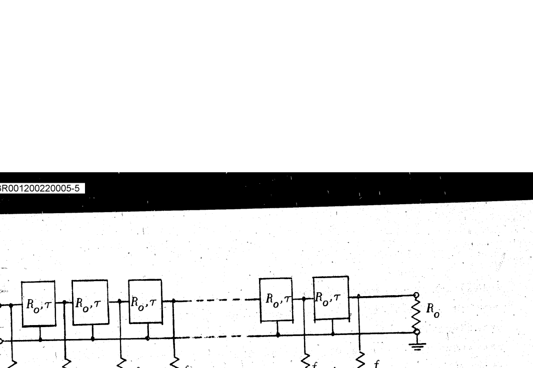

FIG. 5.2.--Interpolation with ideal low-pass filter.

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localized time-domain control with the TDL filter makes experimental alignment of the filter a simple operation. This latter advantage is not a minor consideration. In recent years, considerable emphasis has been placed on the synthesis of networks wherein there exists nearly a one-to-one cor- respondence between element values and the parameters of the prescribed response data. Although this procedure does not yield the optimum design from the standpoint of network economy, this disadvantage is often offset by the simplicity of alignment and synthesis of the networkL.

Of course, the

$$\frac{T}{\pi} \frac{\sin \frac{\pi}{T} t}{t}$$

interpolating pulse is not physically realizable. The requirements for an ideal interpolating pulse are that the function be zero at all sampling instants except one and that the intersample behavior be reasonably smooth. This type of impulse response is physically realizable but not with purely lumped-element networks. Line-lumped networks that meet these requirements will be discussed in the next section. The question remains whether or not a lumped-element filter is still useful. Is it possible, by a readjustment of the tap factors on the TDL, to obtain a time response passing through the prescribed sample values when the interpolating function is the impulse response of a lumped-element network? Using the z-transform repre- sentation for the transfer function of the TDL filter, the overall transfer function can be written as in Eq. 5.01.

$$H(s, z) = F(z)\ G(s) \tag{5.01}$$

where $F(z)$ is a polynomial in z and $G(s)$ is a rational transfer function of the interpolation filter. As shown by Eqs. 3.35-3.41, the z-transform of the output can be represented by the product of $F(z)$ and $G^*(z)$, the z- transform of $g(t)$.

$$H^*(z) = \sum_{k=0}^{N} a_k\ z^k = FG^*(z) = F(z)\ G^*(z) \tag{5.04}$$

$$\sum_{k=0}^{N} a_k\ z^k = \sum_{k=0}^{N} f_k\ z^k \sum_{j=0}^{\infty} g_j\ z^j \tag{5.05}$$

By equating coefficients, N simultaneous equations are obtained.

$$\begin{aligned}
a_o &= f_o g_o \\
a_1 &= f_o g_1 + f_1 g_o \\
a_2 &= f_o g_2 + f_1 g_1 + f_2 g_o \\
a_3 &= f_o g_3 + f_1 g_2 + f_2 g_1 + f_3 g_o \\
&\ \vdots \\
a_N &= \sum_{k=0}^{N} f_k\ g_{N-k}
\end{aligned} \tag{5.06}$$

The g_j's are found from a series expansion of the z-transform of $g(t)$. A good interpolating function will have one predominant term of the time series corresponding to the peak value of $g(t)$. The f_k's (the tap factors of the TDL) can be found in terms of the prescribed a_k's by the simultaneous solution of Eq. 5.06. This solution is easily accomplished by a step-by- step procedure. Note that if all the g_j's are very small compared to the predominant term, the solution for the f_k's might well be done experi- mentally as an alignment operation; the initial settings would correspond to the a_k's.

As an example of a practical interpolating pulse, consider

$$g(t) = \frac{G_o}{n!}\ t^n\ e^{-\alpha t}$$

for $n = 2$ as in Fig. 5.3.

$$g'(t_o) = \frac{G_o}{2}\ t_o\ (-\ \alpha t_o\ e^{-\alpha t_o} + 2e^{-\alpha t_o}) = 0 \tag{5.07}$$

$$g_{max} = g\left(\frac{2}{\alpha}\right) = \frac{2G_o}{\alpha^2}\ e^{-2} \tag{5.08}$$

Let $g_{max} = 1$; then

$$G_o = \frac{e^2\alpha^2}{2} \; ; \quad g(t) = \frac{(\alpha t)^2}{4} e^{2-\alpha t} \; ; \quad G(s) = \frac{e^2\alpha^2}{2(s + \alpha)^3} \qquad (5.09)$$

The parameter α can be adjusted so that the peak of the pulse occurs at a sampling instant, e.g., let $2/\alpha = \tau$.

$$g(t) = \left[\frac{t}{\tau} e^{1-t/\tau}\right]^2 \qquad (5.10)$$

$$g_j = (je^{1-j})^2 \qquad (5.11)$$

$$= 0,\ 1,\ 0.54,\ 0.165,\ 0.04,\ 0.008,\ 0.0015,\ - - -$$

For practical use only five or six sample values of $g(t)$ (Eq. 5.01) are necessary for an accurate representation. The approximation and realization for a specific example are shown in Figs. 5.4 and 5.5. Note that the alignability of the network has been essentially maintained.

B. PULSE FUNCTION IMPULSE RESPONSE

An important class of impulse response functions is the set of time functions having a finite time duration. These are called pulse functions, defined as a bounded time function with a finite number of discontinuities in the function or its derivatives in the interval $T_a \le t \le T_b$ and being identically zero outside this interval. A simple pulse function will be taken to mean a pulse function with no discontinuities in the function or its derivatives in the interval $T_a < t < T_b$

As shown in Chapter IV, line-lumped networks can have pulse function impulse responses. An investigation of the frequency-domain characteristics of the Laplace transform $P(s)$ of the pulse function $p(t)$ leads to some important necessary and sufficient conditions that $P(s)$ be the transform of a pulse function. In particular, it was noted that $P(s)$ must have no poles in the finite part of the s-plane. Furthermore, a sufficient condition

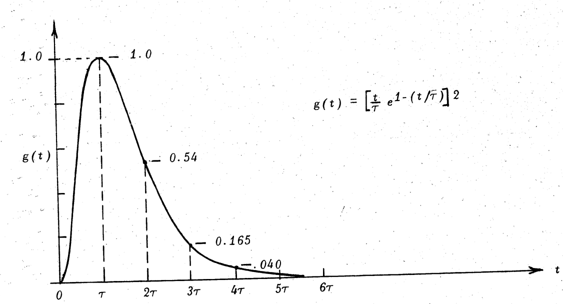

FIG. 5.3.--Interpolating function for lumped-element filter.

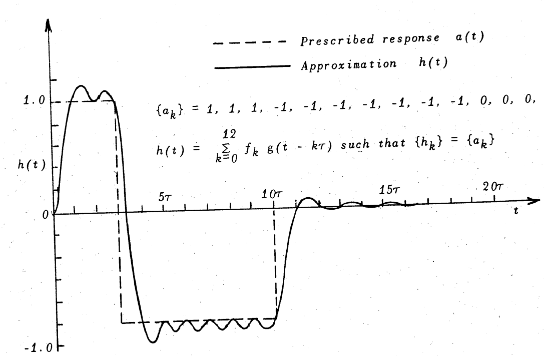

FIG. 5.4.--Prescribed impulse response and time series approximation.

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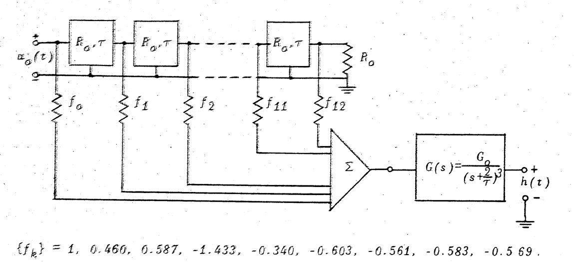


$\{f_k\} = 1,\ 0.460,\ 0.587,\ -1.433,\ -0.340,\ -0.603,\ -0.561,\ -0.583,\ -0.569,$

$-0.575,\ +0.427,\ -0.112,\ +0.013.$

FIG. 5.5.--Network realization of impulse response of Fig. 5.4.

states that

$$P(s,\ z) = G(s)\ F(z) \tag{5.12}$$

where $F(z)$ is a polynomial having zeros in the s-plane which exactly cancel the poles of $G(s)$. The number of zeros of $G(s)$ must be less than the number of poles. A geometric interpretation of Eq. 5.12 is that $F(z)$ provides one or more sets of periodically spaced zeros in vertical lines in the s-plane. The poles of $G(s)$ cancel certain of these conjugate zero pairs resulting in a transfer function $P(s)$ with a zero pattern consisting of one or more partially cancelled zero sets plus the arbitrarily placed zeros of $G(s)$. See Fig. 4.3.

An interesting pulse-function realization requiring only one zero set (and hence a simple $F(z)$) is the simple pulse function approximation $p_a(t)$ to the prescribed $p(t)$ in the interval $0 \leq t \leq T$ with the additional restriction that $|p(T-)| \leq |p(0+)|$. A real, positive parameter α can be defined by Eq. 5.13.

$$p(T-) = \pm\ e^{-\alpha T}\ p(0+) \tag{5.13}$$

Now if $p(t)$ is predistorted to $q(t)$ as in Eq. 5.14 such that $q(T-) = \pm\ q(0+)$, a periodic extention of $q(t)$ can be approximated by a Fourier series.

$$q(t) = e^{\alpha t}\ p(t) \tag{5.14}$$

Let $q'(t)$ be the periodic extension of $q(t)$ in the semi-infinite interval $0 < t < \infty$

$$\left.\begin{aligned} q_a'(t) &= a_o + \sum_{k=1}^{N} \left(a_k \cos \frac{2\pi k t}{T} + b_k \sin \frac{2\pi k t}{T} \right) && t > 0 \\ &= 0 && t < 0 \end{aligned}\right\} \tag{5.15}$$

The a_k's and b_k's are obtained in the normal manner by using the orthogonal properties of the sinusoidal functions.

$$\left.\begin{aligned} a_o &= \frac{1}{T} \int_0^T q(t)\ dt \\ a_k &= \frac{2}{T} \int_0^T q(t) \cos \frac{2\pi k t}{T}\ dt \\ b_k &= \frac{2}{T} \int_0^T q(t) \sin \frac{2\pi k t}{T}\ dt \end{aligned}\right. \tag{5.16}$$

The pulse function $q_a(t)$ is obtained from the ''semi-periodic'' $q_a'(t)$ by the simple relation of Eq. 5.17.

$$q_a(t) = q_a'(t) - q_a'(t - T) \tag{5.17}$$

The approximation to $p(t)$ is found by reversing the predistortion operation.

$$p_a(t) = e^{-\alpha t}\, q_a(t) = e^{-\alpha t}\, q_a'(t) - e^{-\alpha T}\left[e^{-\alpha(t-T)}\, q_a'(t-T)\right]$$

$$= p_a'(t) - e^{-\alpha T}\, p_a'(t-T) \qquad (5.18)$$

$$p_a(t) = \left.\begin{array}{ll} 0 & t < 0 \\ = a_o e^{-\alpha t} + \sum_{k=1}^{N} \left(a_k\, e^{-\alpha t} \cos \frac{2\pi k t}{T} + b_k\, e^{-\alpha t} \sin \frac{2\pi k t}{T}\right) & 0 < t < T \\ = 0 & t > T \end{array}\right\} \qquad (5.19)$$

This completes the approximation operation; the realization proceeds by expressing the Laplace transform of $p_a(t)$.

From Eq. 5.18.

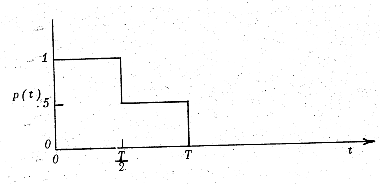
$$P_a(s) = P_a'(s)\,\left[1 - e^{-\alpha T}\, e^{-sT}\right] \qquad (5.20)$$

Apply the shifting theorem to Eq. 5.18.

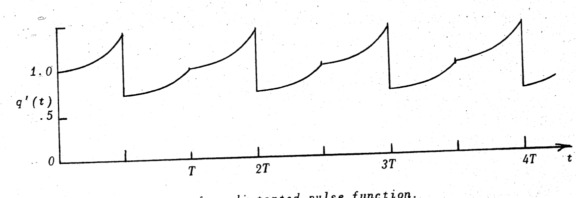
$$P_a'(s) = Q_a'(s + \alpha) \qquad (5.21)$$

But

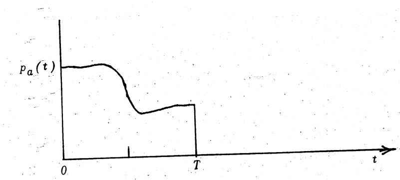
$$Q_a'(s) = \frac{a_o}{s} + \sum_{k=1}^{N} \frac{a_k\, s}{s^2 + \left(\frac{2\pi k}{T}\right)^2} + \frac{b_k \frac{2\pi k}{T}}{s^2 + \left(\frac{2\pi k}{T}\right)^2} \qquad (5.22)$$



a) Prescribed pulse function, $p(t)$.



b) Periodic extension of predistorted pulse function.



c) Approximation to (a) resulting from representing (b) by the first few terms of a Fourier series expansion.

FIG. 5.6.--Pulse function approximation by Fourier series method.

So that

$$P'_a(s) = \frac{a_o}{s + \alpha} + \sum_{k=1}^{N} \frac{a_k(s + \alpha) + b_k \frac{2\pi k}{T}}{(s + \alpha)^2 + \left(\frac{2\pi k}{T}\right)^2} \tag{5.23}$$

$P'_a(s)$ is rational in s with all its poles in the LHP hence $P'_a(s)$ can be realized as the transfer function of a lumped-element filter. The zeros of $1 - e^{-(s+\alpha)T}$ cancel the $2N + 1$ simple poles of Eq. 5.20. The transform of the simple pulse function can be written in the form of Eq. 5.12.

$$P_a(s, z) = P'_a(s) \; [1 - e^{-\alpha T} z^m] \tag{5.24}$$

where

$$T = m\tau$$

The transfer function, $F(z) = K[1 \pm e^{-\alpha T} z^m]$ can be realized as a voltage transfer ratio by the simple L-section of Fig. 5.8. Notice that if the ratio $p(T-)/p(0+)$ is positive, the semi-periodic extension $q'(t)$ will be continuous at the points $t = nT$. This means that the series for $p(t)$ will converge towards $p(0+)$ and $p(T-)$ at $t = 0+$ and $t = T-$, hence discontinuities in the impulse response can be realized at the leading and training edges of the simple pulse function. If, on the other hand, the ratio $p(T-)/p(0+)$ is negative, the semi-periodic extension will be discontinuous at $t = nT$ and the series approximation for $p(t)$ will go through zero at $t = 0$ and $t = T$. If it is desirable that the leading and trailing edges of this type of impulse response be very square, a somewhat more involved realization can be used which permits discontinuities in $p_a(t)$ at $t = 0$ and $t = T$. If the even periodic extension $q''(t)$ of the predistorted pulse function $q(t)$ is formed, the resulting semi-periodic function will be continuous at $t = nT$. The fundamental period will be $2T$. Since the periodic extension is even, the approximation $q''_a(t)$ can be a Fourier cosine series. The amount of predistortion, determined by α, is now somewhat arbitrary since any even periodic extension is continuous at $t = nT$.

$$P'_a(s) = \sum_{k=0}^{N} \frac{a_k(s + \alpha) + b_k \frac{2\pi k}{T}}{(s + \alpha)^2 + \left(\frac{2\pi k}{T}\right)^2} \qquad F(z) = 1 - e^{-\alpha T} z^m$$

where $T = m\tau$

FIG. 5.7.--Transfer function to realize pulse function impulse response of Fig. 5.6(c).

$$\frac{V_2}{V_1}(z) = \frac{1}{2}\,[1 + kz^m]\,; \qquad k = \frac{R - R_o}{R + R_o}$$

FIG. 5.8.--L-section network realization of the voltage transfer ratio, $F(z) = K[1 \pm e^{-\alpha T} z^m]$.

$$q''_a(t) = \sum_{k=0}^{N} a_k \cos \frac{k\pi t}{T} \tag{5.25}$$

$$p_a(t) = \left[\sum_{k=0}^{N} a_k \, e^{-\alpha t} \cos \frac{k\pi t}{T} \right] u_{-1}(t)$$

$$- e^{-\alpha T} \left[\sum_{k=0}^{N} a_k (-1)^k \, e^{-\alpha(t-T)} \cos \frac{k\pi(t - T)}{T} \right] u_{-1}(t - T) \tag{5.26}$$

$$\left.\begin{aligned} p_a(t) &= 0 && t < 0 \\ &= \sum_{k=0}^{N} a_k \, e^{-\alpha t} \cos \frac{k\pi t}{T} && 0 < t < T \\ &= 0 && t > T \end{aligned}\right\} \tag{5.27}$$

Now to realize the network, the transfer function is found from the Laplace transform of Eq. 5.26.

$$P_a(s) = \sum_{j=0}^{N/2} \frac{a_{2j} \, s}{(s + \alpha)^2 + \left(\frac{2j\pi}{T}\right)^2} \left(1 - e^{-(s+\alpha)T}\right)$$

$$+ \sum_{j=0}^{N/2} \frac{a_{2j+1} \, s}{(s + \alpha)^2 + \left(\frac{(2j + 1)\pi}{T}\right)^2} \left(1 + e^{-(s+\alpha)T}\right) \tag{5.28}$$

$$P_a(s, z) = P_{a1}(s) \, [1 - e^{-\alpha T} z^m] + P_{a2}(s) \, [1 + e^{-\alpha T} z^m] \tag{5.29}$$

Note that the zero pattern is no longer periodic in this case since the transfer function is a sum of terms of the form of Eq. 5.24.

Obviously, a more general pulse function could be constructed from the sum of several simple pulse functions having arbitrary shape and duration. In particular, the previous results suggest that the mathematical models used for interpolation filters in Chapter III might be physically realizable with line-lumped networks. A considerable improvement in the realization procedure for an arbitrary impulse response by the TDL-interpolation filter method results when the impulse response of the interpolation filter can be realized as a pulse function. Basically the purpose of the interpolation filter is to operate on the past sample values of the input sequence such that the output is extended to the succeeding sample value in some logical manner. This property of the filter is called its memory since the future output is constructed from a knowledge of previously received sample values. For obvious reasons, the impulse response of a filter is often called the ''memory curve'' of the filter. If the filter is to perform any reasonably good interpolation between the *kth* and *(k + 1)th* sample values, the *(k + 1)th* sample value must be known. This seems to imply that prediction is required of the filter since the *(k + 1)th* has not yet been received at the input of the filter. Physically realizable filters cannot have an output before being excited so that prediction is impossible, however, if a time delay of one sampling interval is allowed in the output of the filter, the *(k + 1)th* sample value can contribute to the interpolation between $k\tau$ and $(k + 1)\tau$. In other words, after a sufficient delay the *(k + 1)th* sample value becomes part of the memory of the filter. In general, as the delay between the input sequence and the output is increased the interpolation between sample values can be improved.

An example of a useful type of interpolation is a polynomial in t. The coefficients of an *nth* degree polynomial can be adjusted such that the polynomial passes through any arbitrary set of n sample values. The interpolation functions of Fig. 3.12 are the simplest examples of this type of interpolation. The rectangular pulse might be considered as polynomial interpolation of zero degree. It merely holds the output constant at a value equal to the *kth* sample value until the *(k + 1)th* sample is received. No prediction is involved and the filter has a memory only of the last sample value. As a result, the staircase approximation of Fig. 3.11 is very crude. A first-degree interpolation may consist of fitting linear slopes between samples as in Eq. 5.30.

$$h(t) = a_o + a_1 t \; ; \quad k\tau \le t \le (k+1)\tau$$

such that

$$a_o + a_1 k\tau = f_k \qquad (5.30)$$

$$a_o + a_1 (k+1)\tau = f_{k+1}$$

Solving for the a's, we get

$$a_o = \frac{f_k (k+1)\tau - f_{k+1}\, k\tau}{\tau}$$

$$\qquad (5.31)$$

$$a_1 = \frac{f_{k+1} - f_k}{\tau}$$

Then

$$h(t) = \frac{1}{\tau}\Big[-(t - (k+1)\tau)\, f_k + (t - k\tau)\, f_{k+1}\Big] \qquad (5.32)$$

$$k\tau \le t \le (k+1)\tau$$

But from Eq. 5.03

$$h(t) = f_k g_1(t - k\tau) + f_{k+1}\, g_1(t - (k+1)\tau) \qquad (5.33)$$

$$k\tau \le t \le (k+1)\tau$$

Combine 5.32 and 5.33 and solve for $g(t)$:

$$g_1(t) = \frac{1}{\tau}(t + \tau) \; ; \qquad -\tau \le t \le 0 \; .$$

$$\qquad (5.34)$$

$$= -\frac{1}{\tau}(t - \tau) \; ; \qquad 0 \le t \le \tau$$

As expected, this is a triangular pulse function of duration 2τ and peak value of 1, as in Fig. 5.9b. Delaying this function by τ makes it physically realizable as the impulse response of a network having the transfer function,

$$G_1(s, z) = \frac{(1 - z)^2}{\tau s^2} \qquad (5.35)$$

In a similar manner, a second degree interpolation can be developed by making the interpolation in the interval, $k\tau \le t \le (k+1)\tau$, a second degree polynomial passing through f_{k-1}, f_k, f_{k+1} as in Eq. 5.36.

$$h(t) = a_o + a_1 t + a_2 t^2 \; ; \quad k\tau \le t \le (k+1)\tau$$

such that

$$a_o + a_1(k-1)\tau + a_2(k-1)^2\tau^2 = f_{k-1}$$

$$a_o + a_1 k\tau + a_2 k^2\tau^2 = f_k \qquad (5.36)$$

$$a_o + a_1(k+1)\tau + a_2(k+1)^2\tau^2 = f_{k+1}$$

Express the a's in terms of the f_k's; then

$$h(t) = \frac{1}{2\tau^2}\,[(t - k\tau)(t - (k+1)\tau)\, f_{k-1} - 2(t - (k-1)\tau)(t - (k+1)\tau)\, f_k$$

$$+ (t - k\tau)(t - (k-1)\tau)\, f_{k+1}] \qquad (5.37)$$

$$k\tau \le t \le (k+1)\tau$$

But from Eq. 5.03

$$h(t) = f_{k-1}\, g_2(t - (k-1)\tau) + f_k\, g_2(t - k\tau) + f_{k+1}\, g_2(t - (k+1)\tau) \qquad (5.38)$$

$$k\tau \le t \le (k+1)\tau$$

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and solving for $g_2(t)$, we get

$$
\begin{aligned}
g_2(t) &= \frac{1}{2\tau^2}\left[(t+\tau)(t+2\tau)\right]; \quad -\tau \le t \le 0 \\
&= -\frac{1}{\tau^2}\left[(t+\tau)(t-\tau)\right]; \quad 0 \le t \le \tau \qquad (5.39) \\
&= \frac{1}{2\tau^2}\left[(t-\tau)(t-2\tau)\right]; \quad \tau \le t \le 2\tau
\end{aligned}
$$

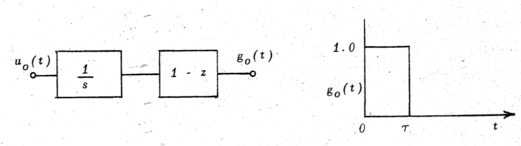
Fig. 5.9c shows $g_2(t)$ with a delay of τ. The transfer function of the interpolation filter is given by

$$G_2(s,\ z) = \frac{s\tau + 2}{2\tau^2 s^3}\ (1 - z)^3 \qquad (5.40)$$

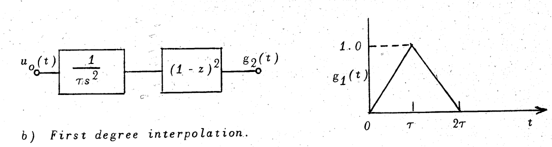
This type of interpolation with polynomials in t is known as Lagrangian interpolation. The transfer functions are physically realizable with line-lumped networks to the extent that a multiple order pole can be placed arbitrarily close to the origin in the s-plane. A more precise procedure can be developed by multiplying the Lagrangian interpolating polynomials by $e^{-\alpha t}$ and preceding as before. The resulting transfer function will then have a multiple order pole at $s = -\alpha$.

C. SEGMENTAL REALIZATION OF IMPULSE RESPONSE

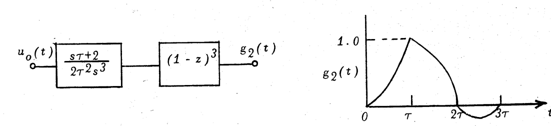
It was noted in Chapter IV that the impulse response of a line-lumped network consists of segments of time functions having rational Laplace transforms between critical values of time or ''break points'' as determined by the lengths and configuration of the delay lines in the network. However, these break points (where the impulse response or its derivatives may be discontinuous) do not have to be spaced at equal time intervals. In fact, a considerable saving on the number of taps required in the TDL filter realization of a impulse response in which the intervals between break points are largely different can be accomplished by a somewhat different procedure. Suppose, for example, that the prescribed impulse response



a) *Zero degree interpolation.*



b) *First degree interpolation.*

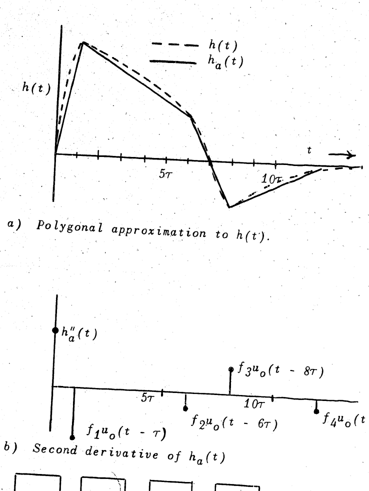


c) *Second degree interpolation.*

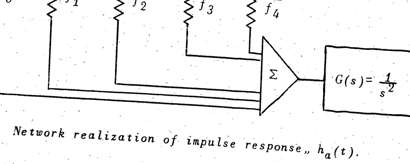
FIG. 5.9.--Polynomial interpolation filters.

can be approximated by a polygonal function as in Fig. 5.10. Two consecutive differentiations of $h_a(t)$ yields the impulse sequence, $f(t)$, whose transfer function, $F(z)$, can be realized by a TDL filter with unequal time delays between taps. If this filter is cascaded with a filter capable of a double integration, $G(s) = 1/s^2$, then the impulse response of the combination is $h_a(t)$.

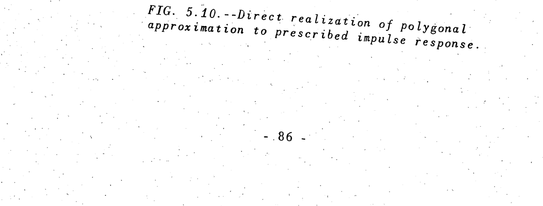
A more general procedure for the realization of a segmental impulse response involves a separate approximation in each interval by a sum of exponentials. Usually the approximation is not critically dependent on the values chosen for the time constants of the individual exponentials; hence it is reasonable to presume that the same set of exponential functions can be used for approximation in each interval as in Eq. 5.41.



a) Polygonal approximation to $h(t)$.



b) Second derivative of $h_a(t)$



c) Network realization of impulse response, $h_a(t)$.

FIG. 5.10.--Direct realization of polygonal approximation to prescribed impulse response.

$$
\left.
\begin{aligned}
h_a(t) &= \sum_{k=1}^{N} a_{1k}\, e^{s_k t} \quad ; \quad 0 < t < T_1 \\
&= \sum_{k=1}^{N} a_{2k}\, e^{s_k (t - T_1)} ; \quad T_1 < t < T_2 \\
&= \sum_{k=1}^{N} a_{3k}\, e^{s_k (t - T_2)} ; \quad T_2 < t < T_3 \\
&\;\;\vdots \\
&= \sum_{k=1}^{N} a_{mk}\, e^{s_k (t - T_{m-1})} ; \quad T_{m-1} < t < \infty
\end{aligned}
\right\} \qquad (5.41)
$$

Taking the Laplace transform of Eq. 5.41. we obtain

$$
\left.
\begin{aligned}
H_a(s) = &\sum_{k=1}^{N} \frac{a_{1k}}{s - s_k} \left(1 - e^{s_k T_1}\, e^{-sT_1}\right) \\
+ &\sum_{k=1}^{N} \frac{a_{2k}}{s - s_k} \left(e^{-sT_1} - e^{s_k (T_2 - T_1)}\, e^{-sT_2}\right) \\
+ &\sum_{k=1}^{N} \frac{a_{3k}}{s - s_k} \left(e^{-sT_2} - e^{s_k (T_3 - T_2)}\, e^{-sT_3}\right) \\
&\;\;\vdots \\
+ &\sum_{k=1}^{N} \frac{a_{mk}}{s - s_k} \left(e^{-sT_{m-1}}\right)
\end{aligned}
\right\} \qquad (5.42)
$$

where $Re\ s_k < 0$

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Rearranging terms, we have

$$
\left.
\begin{aligned}
H_a(s) = {} & \sum_{k=1}^{N} \frac{a_{1k}}{s - s_k} + \sum_{k=1}^{N} \frac{a_{2k} - a_{1k}\, e^{s_k T_1}}{s - s_k}\, e^{-sT_1} \\
& + \sum_{k=1}^{N} \frac{a_{3k} - a_{2k}\, e^{s_k (T_2 - T_1)}}{s - s_k}\, e^{-sT_2} + \cdots \\
& \cdots + \sum_{k=1}^{N} \frac{a_{mk} - a_{(m-1)k}\, e^{s_k (T_{m-1} - T_{m-2})}}{s - s_k}\, e^{-sT_{m-1}}
\end{aligned}
\right\} \quad (5.43)
$$

or

$$
H_a(s,\ z) = G_o(s) + G_1(s)\, z^{T_1/\tau} + G_2(s)\, z^{T_2/\tau} + \cdots G_{m-1}(s)\, z^{T_{m-1}/\tau} \qquad (5.44)
$$

where τ is chosen to be a common submultiple of all the break times, T_j. The relatively simple form of the transfer function of Eq. 5.44 is a result of approximation in each interval by the same set of exponential functions. All the G's have the same pole locations in the s-plane. The pole locations, s_k may be complex but they must be taken in conjugate pairs. Furthermore, if $s_k = a_k \pm j\beta_k$ then $\beta_k(T_j - T_{j-1}) = n\pi$ for all k and all j in order that the constants in Eq. 5.43 may be real, as required for physical realizability.

The approximation problem consists of choosing a suitable set of time constants, s_k, and then finding the a_{jk}'s according to some suitable error criterion. The problem of approximating an arbitrary time function over the semi-infinite interval, $0 < t < \infty$, by a finite sum of exponential functions has received considerable attention. Kautz[1] has shown a method for generating a set of functions orthonormal over the interval $0 < t < \infty$, consisting of linear combinations of the $e^{s_k t}$. With line-lumped networks, however, the

[1] W. H. Kautz, *"Networks synthesis for specified transient response,"* TR No.209, Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts, April 1952.

approximations can be made over finite time intervals, thus allowing for much better error control within each interval. It might be useful to develop a method for generating orthonormal sets of functions for a finite time interval. Then the coefficients a_{jk} would be found by following the usual procedure for making orthonormal expansions and the error would be controlled in a mean square sense.[1] Approximation in a finite time interval allows another procedure which results in an approximating function passing through the prescribed sample values in a given interval. The z-transform of the prescribed response in the interval $T_{j-1} < t < T_j$ is given by a polynomial in z as shown in the right-hand side of Eq. 5.45. The z-transform of the approximating function in this interval is the ratio of two polynomials in z as in the left-hand side of Eq. 5.45. The problem of solving for n_j's and d_j's appears to be the familiar Padé approximation problem mentioned in Chapter III. The problem is considerably simplified, however, since the d_j's are already determined by the choice of the s_k. Hence the n_j's are given directly as shown in Eq. 5.46. If N exponential functions are used in the approximation, then N sample values can be prescribed in each interval.

$$
\frac{N_j(z)}{D_j(z)} = \frac{n_{jo} + n_{j1}z + n_{j2}z^2 + \cdots n_{j(N-1)}z^{N-1}}{d_{jo} + d_{j1}z + d_{j2}z^2 + \cdots + z^N} = h_{jo} + h_{j1}z + h_{j2}z^2 + \cdots \qquad (5.45)
$$

$$
\begin{aligned}
n_{jo} + n_{j1}z + n_{j2}z^2 + \cdots n_{j(N-1)}z^{N-1} = {} & (d_{jo} + d_{j1}z + \cdots + z^N) \\
& (h_{jo} + h_{j1}z + h_{j2}z^2 + \cdots)
\end{aligned}
$$

$$
\begin{aligned}
n_{jo} &= d_{jo}h_{jo} \\
n_{j1} &= d_{jo}h_{j1} + d_{j1}h_{jo} \\
n_{j2} &= d_{jo}h_{j2} + d_{j1}h_{j1} + d_{j2}h_{jo} \\
n_{j3} &= d_{jo}h_{j3} + d_{j1}h_{j2} + d_{j2}h_{j1} + d_{j3}h_{jo} \\
&\vdots \\
n_{j(N-1)} &= \sum_{i=o}^{N-1} d_{ji}h_{j(N-1-i)}
\end{aligned}
\qquad (5.46)
$$

[1] Courant and Hilbert, *Methods of Mathematical Physics*, Interscience, Vol. 1, New York, N. Y. 1953, Chapter II.

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If $N_j(z)/D_j(z)$ is expanded in partial fractions, the Laplace transform of the approximating function can be identified in partial fraction form and the a_{jk}'s are obtained directly.

$$\frac{N_j(z)}{D_j(z)} = \sum_{k=1}^{N} \frac{b_{jk}}{z - z_k} \longrightarrow \sum_{k=1}^{N} - \frac{b_{jk}\, e^{s_k \tau}}{s - s_k} \qquad (5.47)$$

where

$$z_k = e^{-s_k \tau}, \qquad a_{jk} = - b_{jk}\, e^{s_k \tau}$$

One realization for this type of impulse response is obvious from an inspection of the transfer function (Eq. 5.44). This realization can be a TDL filter whose tap factors, instead of being constants, are rational functions of s as shown in Fig. 5.11. All the G's have the same pole locations but each zero pattern is different according to the coefficients used in the approximating function in the particular interval.

D. REALIZATION OF A TRANSFER FUNCTION RATIONAL IN z

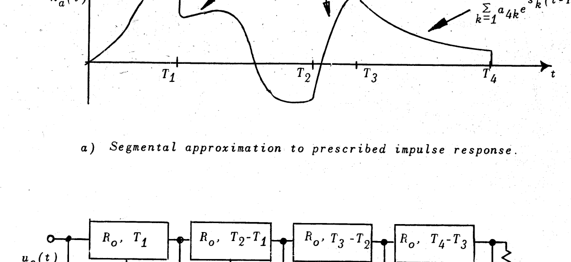
Previous realizations for transfer functions rational in z were limited to those cases where $F(z)$ was a polynomial in z; hence $F(z)$ had no poles in the finite part of the z-plane. This implies that the impulse response of a network having a transfer function of this form will consist of a finite impulse sequence, and the most direct realization is the TDL filter. Conversely, if $F(z)$ has poles then the impulse response will be an infinite impulse sequence.

The ability to realize a transfer function rational in z by a network containing delay lines and resistors allows a radically different approach to the design of a network having a prescribed output time response under the influence of a given input function. This procedure is known generally as ''time-domain equalization.''[1,2] The given input and prescribed output of Fig. 5.12 can be given a time series (z-transform) representation. If the time-domain equalizer has a transfer function given by Eq. 5.48, then

[1] D. C. Espley, ''*The exact solution for transient distortion in networks,*'' Electronic Engineering, Vol. 22, March 1950, pp. 81-87.

[2] D. C. Espley, ''*Waveform systems and time equalizers,*'' Wireless Engr., Vol. 28, 1951, p. 251.

a) *Segmental approximation to prescribed impulse response.*



b) *Network realization for $h_a(t)$*

FIG. 5.11.--Realization of segmental impulse response.

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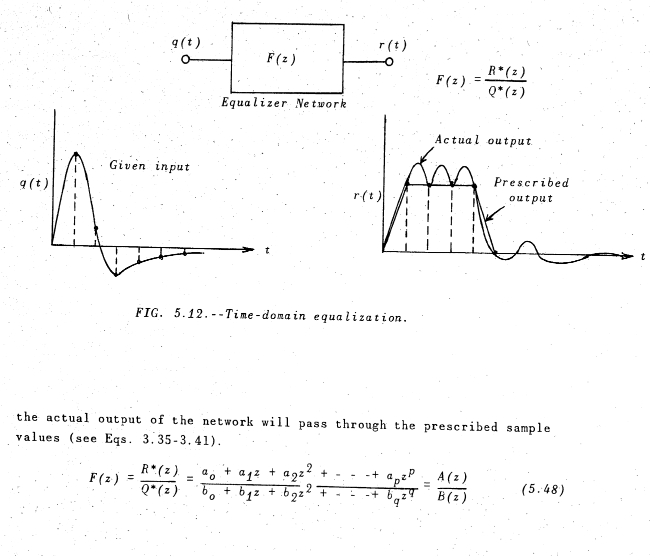


FIG. 5.12.--Time-domain equalization.

the actual output of the network will pass through the prescribed sample values (see Eqs. 3.35-3.41).

$$F(z) = \frac{R^*(z)}{Q^*(z)} = \frac{a_o + a_1 z + a_2 z^2 + - - -+ a_p z^p}{b_o + b_1 z + b_2 z^2 + - - -+ b_q z^q} = \frac{A(z)}{B(z)} \qquad (5.48)$$

An obvious restriction on the physical realizability of the network is that the z-transform of the output have no poles inside the unit circle on the z-plane unless the z-transform of the input has the same poles inside the unit circle. Similarly, the z-transform of the input must have no zeros inside the unit circle unless the output has the same zeros.

Note that localized time-domain control in the response function can be accomplished by manipulation of a single parameter in the transfer function, $F(z)$. No such possibility exists for lumped-element equalizers. Also, the representation of the time functions by a time series is much simpler than representation by a sum of time functions having rational Laplace transforms, especially if the time functions are given in terms of numerical data.

The transfer function $F(z)$ in Eq. 5.48 will be realized by a network containing only resistors and delay-line elements of commensurable length. It would be very desirable to develop a realization procedure which does not require factorization of the numerator and denominator polynomials of $F(z)$. One such development requires that an all-zero impedance function $Z_A(z)$, can be realizable.

$$Z_A(z) = a_o + a_1 z + a_2 z^2 +- - - a_p z^p \qquad (5.49)$$

$Z_A(z)$ must be a positive-real function hence $Re\ Z_A(z) \geqq 0$ on $|z| = 1$, as in Eq. 5.50.

$$Re\ Z_A(\theta) = a_o + a_1 \cos\theta + a_2 \cos 2\theta + - - - + a_p \cos p\theta \geq 0 \qquad (5.50)$$

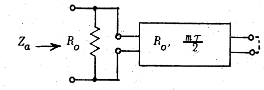
for

$$z = e^{j\theta}$$

A useful sufficient condition that Eq. 5.50 is satisfied is given by

$$\sum_{n=1}^{p} |a_n| \leq a_o \qquad (5.51)$$

$Z_A(z)$ can be realized by a series combination of impedances of the form shown in Fig. 5.13.



$Z_a = \frac{R_o}{2}[1 + z^m]$ *for open-circuit termination*

$Z_a = \frac{R_o}{2}[1 - z^m]$ *for short-circuit termination*

FIG. 5.13.--Realization of impedance function, $\frac{R_o}{2}[1 \pm z^m]$.

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Let

$$Z_A(z) = R + \frac{R_{o1}}{2}(1 \pm z) + \frac{R_{o2}}{2}(1 \pm z^2) + \cdots + \frac{R_{op}}{2}(1 \pm z^p) \quad (5.52)$$

By comparison with Eq. 5.49 we have

$$|a_n| = \frac{R_{on}}{2}$$

$$a_o = \sum_{n=1}^{p} \frac{R_{on}}{2} + R = \sum_{n=1}^{p} |a_n| + R \quad (5.53)$$

The condition of Eq. 5.51 assures that $R \geq 0$ so that $Z_A(z)$ is physically realizable as shown in Fig. 5.14.

An all-pole impedance can be realized by essentially the same procedure by virtue of the duality of impedance and admittance functions. An admittance function of the same form as Eq. 5.49 can be realized as a parallel combination of the admittances shown in Fig. 5.15.

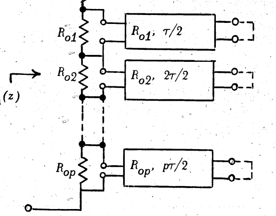
$$Y_B(z) = b_o + b_1 z + b_2 z^2 + \cdots + b_q z^q \quad (5.54)$$

Let

$$Y_B(z) = \frac{1}{R} + \frac{1}{2R_{o1}}(1 \pm z) + \frac{1}{2R_{o2}}(1 \pm z^2) + \cdots + \frac{1}{2R_{oq}}(1 \pm z^q) \quad (5.55)$$

where

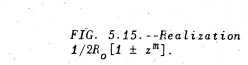
$$|b_n| = \frac{1}{2R_{on}}, \qquad b_o = \sum_{n=1}^{q} \frac{1}{2R_{on}} + \frac{1}{R} = \sum_{n=1}^{q} |b_n| + \frac{1}{R}$$



Open-circuit termination for a_n positive.

Short-circuit termination for a_n negative.

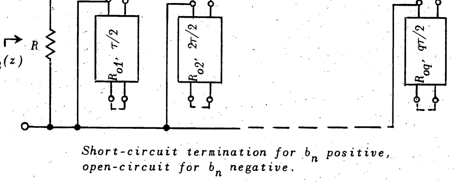
FIG. 5.14.--Realization of all-zero impedance function.



$Y_b = \frac{1}{2R_o}[1 - z^m]$ *for open-circuit termination*

$Y_b = \frac{1}{2R_o}[1 + z^m]$ *for short-circuit termination*

FIG. 5.15.--Realization of admittance function, $1/2R_o[1 \pm z^m]$.



Short-circuit termination for b_n positive, open-circuit for b_n negative.

FIG. 5.16.--Realization of all-pole impedance function.

Let

$$Z_A(z) = R + \frac{R_{o1}}{2}(1 \pm z) + \frac{R_{o2}}{2}(1 \pm z^2) + \cdots + \frac{R_{op}}{2}(1 \pm z^p) \quad (5.52)$$

By comparison with Eq. 5.49 we have

$$|a_n| = \frac{R_{on}}{2} \quad (5.53)$$

$$a_o = \sum_{n=1}^{p} \frac{R_{on}}{2} + R = \sum_{n=1}^{p} |a_n| + R$$

The condition of Eq. 5.51 assures that $R \geq 0$ so that $Z_A(z)$ is physically realizable as shown in Fig. 5.14.

An all-pole impedance can be realized by essentially the same procedure by virtue of the duality of impedance and admittance functions. An admittance function of the same form as Eq. 5.49 can be realized as a parallel combination of the admittances shown in Fig. 5.15.

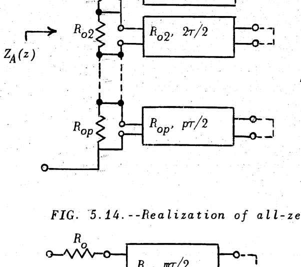
$$Y_B(z) = b_o + b_1 z + b_2 z^2 + \cdots + b_q z^q \quad (5.54)$$

Let

$$Y_B(z) = \frac{1}{R} + \frac{1}{2R_{o1}}(1 \pm z) + \frac{1}{2R_{o2}}(1 \pm z^2) + \cdots + \frac{1}{2R_{oq}}(1 \pm z^q) \quad (5.55)$$

where

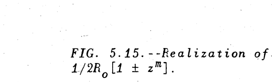
$$|b_n| = \frac{1}{2R_{on}}, \qquad b_o = \sum_{n=1}^{q} \frac{1}{2R_{on}} + \frac{1}{R} = \sum_{n=1}^{q} |b_n| + \frac{1}{R}$$



Open-circuit termination for a_n positive.

Short-circuit termination for a_n negative.

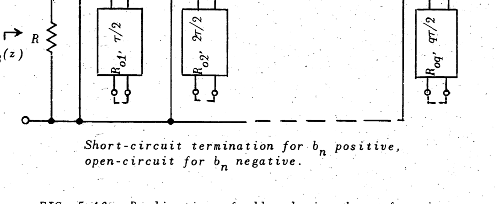
FIG. 5.14.--*Realization of all-zero impedance function.*



$Y_b = \frac{1}{2R_o}[1 - z^m]$ *for open-circuit termination*

$Y_b = \frac{1}{2R_o}[1 + z^m]$ *for short-circuit termination*

FIG. 5.15.--*Realization of admittance function, $1/2R_o[1 \pm z^m]$.*



Short-circuit termination for b_n positive, open-circuit for b_n negative.

FIG. 5.16.--*Realization of all-pole impedance function.*

Then

$$Z_B(z) = \frac{1}{b_o + b_1 z + b_2 z^2 + \cdots + b_q z^q} \tag{5.56}$$

The fact that a polynomial impedance function is realizable allows a direct realization of a voltage transfer ratio in the form of Eq. 5.48. Consider the voltage transfer ratio of the network of Fig. 5.17.

$$\frac{V_2}{V_1}(z) = \frac{k_1 Z_1 + k_2(Z_1 + Z_2) + k_3(Z_1 + Z_2 + Z_3) + \cdots k_n \sum_{i=1}^{n} Z_i}{\sum_{i=1}^{n} Z_i} \tag{5.57}$$

If ΣZ_i is constructed to be the polynomial impedance function, $B(z)$ as in Fig. 5.18, the coefficients of $A(z)$ can be arbitrarily chosen by proper adjustment of the tap factors, k_j, to the summing amplifier. As with the TDL filter, it is assumed that the tapping resistors do not load the network and that the tap factors can be positive or negative depending on how they are connected to the summing amplifier.

$$F(z) = \frac{A(z)}{B(z)} = \frac{a_o + a_1 z + a_2 z^2 + \cdots a_p z^p}{b_o + b_1 z + b_2 z^2 + \cdots b_q z^q} \tag{5.48}$$

From the network of Fig. 5.18,

$$\frac{V_2}{V_1}(z) = \frac{k_o R + k_1[R + |b_1|(1 \pm z)] + k_2[R + |b_2|(1 \pm z^2) + |b_1|(1 \pm z)] + \cdots k_q B(z)}{b_o + b_1 z + b_2 z^2 + \cdots b_q z^q} \tag{5.58}$$

Comparing Eq. 5.58 with Eq. 5.48, the k_j tap factors can be expressed in terms of the a_j's.

$$
\begin{aligned}
a_q &= k_q\, b_q \\
a_{q-1} &= (k_{q-1} + k_q)\, b_{q-1} \\
a_{q-2} &= (k_{q-2} + k_{q-1} + k_q)\, b_{q-2} \\
&\;\;\vdots \\
a_3 &= b_3 \sum_{n=3}^{q} k_n \\
a_2 &= b_2 \sum_{n=2}^{q} k_n \\
a_1 &= b_1 \sum_{n=1}^{q} k_n \\
a_o &= \left(k_o + \frac{a_1}{b_1}\right)\left(b_o - \sum_{n=1}^{q} |b_n|\right) + \sum_{n=1}^{q} \frac{a_n |b_n|}{b_n}
\end{aligned}
\tag{5.59}
$$

This method of realization of a transfer function has the distinct advantage that factorization of polynomials is not required and also the network has a high degree of alignability. The zeros of the transfer function are not restricted. The denominator of $F(z)$ must satisfy the condition of Eq. 5.51.

$$\sum_{n=1}^{q} |b_n| \leq b_o \tag{5.51}$$

Note that this is a somewhat stronger restriction than that $F(z)$ have no poles inside the unit circle. Also, this realization is valid only for $p \leq q$, however, if $p > q$ a division of the numerator by the denominator will yield a polynomial of degree p-q plus a remainder of degree q as in Eq. 5.60.

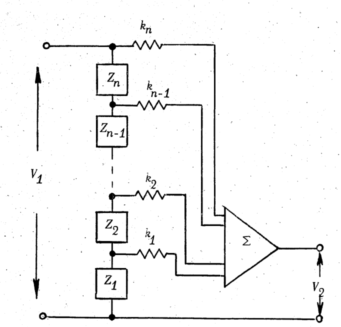


FIG. 5.17.--Network realization of voltage transfer function having poles at the zeros of $\sum_{i=1}^{n} Z_i$ and arbitrarily placed zeros determined by the adjustment of the tap factors, k_i.

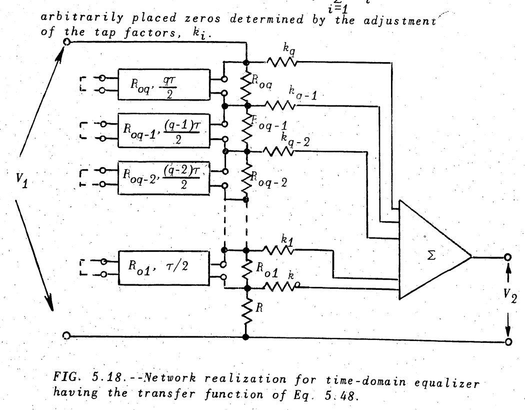


FIG. 5.18.--Network realization for time-domain equalizer having the transfer function of Eq. 5.48.

$$F(z) = c_{p-q}\, z^{p-q} + \cdots + c_1 z + \frac{a'_o + a'_1 z + a'_2 z^2 + \cdots + a'_q z^q}{b_o + b_1 z + \cdots + b_q z^q} \tag{5.60}$$

The polynomial part can be realized by a TDL filter and its output added to the output from the network having the remainder as a transfer function. The same summing amplifier can be used for both networks.

Another interesting procedure for the realization of a transfer function rational in z results from the linear bilateral transformation of Eq. 5.61 which maps the region inside the unit circle in the z-plane into the RHP in the w-plane.

$$w = \frac{1 - z}{1 + z} \tag{5.61}$$

It might be expected that the w-plane properties of a delay-line-resistor network would be similar to the s-plane properties of a lumped element network. In fact, the correspondence is remarkably good.[1,2] The transformation of Eq. 5.62 represents the mapping of the s-plane into the w-plane.

$$w = \tanh \frac{s\tau}{2} \tag{5.62}$$

The horizontal strip between $-j\ \pi/\tau$ and $+j\ \pi/\tau$ in the s-plane maps into the entire w-plane hence the transfer function must have a finite number of poles and zeros in the w-plane. The path from $-j\ \pi/\tau$ to $+j\ \pi/\tau$ on the ω axis in the s-plane maps into the imaginary axis of the w-plane. The utility of the transformation of Eq. 5.61 is in the analogy of the impedances of short-circuit and open-circuit terminated lines with the impedances of inductors and capacitors respectively as shown in Fig. 5.19. The implication is that standard synthesis procedures for realizing transfer functions rational in s by lumped element networks can be applied directly for realization of a transfer function rational in w (hence in z) by networks containing only resistors and open- and short-circuited delay lines. The L-section networks of Table II for the realization of individual poles and zero-pole pairs in w indicate the close

[1] P. I. Richards, *"Resistor-transmission-line circuits,"* Proc. IRE, Vol. 36, February 1948, pp. 217-220.

[2] P. I. Richards, *"A specialized class of functions with positive real part in a half-plane,"* Duke Math. Jour. Vol. 14, September 1947, pp. 777-786.

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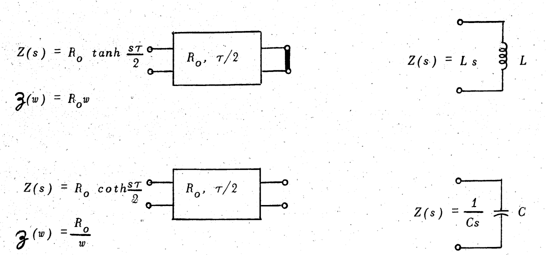


FIG. 5.19.--The analogy of the impedances of open- and short-circuit terminated delay lines to lumped reactive elements by the transformation $w = \tanh(s\tau/2)$.

analogy to lumped element networks, Richards presents a detailed study of the properties of realizable impedance functions rational in w. In particular, he shows a realization for a reactance function as a cascade combination of delay line elements. Appendix C gives an outline of the method.

The following examples should illustrate the synthesis procedures suggested in this section. Suppose that the z-transforms of the input and output time functions of Fig. 5.12 are given by $Q^*(z)$ and $R^*(z)$ respectively.

$$Q^*(z) = z(1 + 0.2z - 0.3z^2 - 0.2z^3 - 0.1z^4)$$

$$R^*(z) = z(1 + z + z^2 + z^3)$$

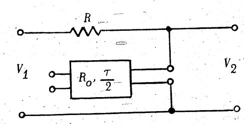
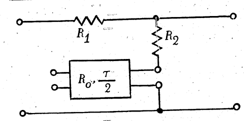
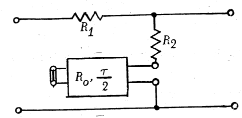
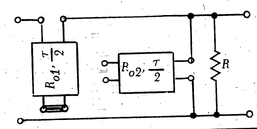
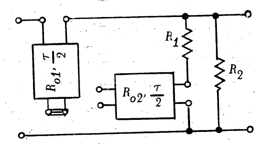
Then

$$F(z) = \frac{A(z)}{B(z)} = \frac{1 + z + z^2 + z^3}{1 + 0.2z - 0.3z^2 - 0.2z^3 - 0.1z^4}$$

The realizability condition of Eq. 5.51 is satisfied since

$$\sum_{n=1}^{4} |b_n| = 0.8 < b_o$$

TABLE II.--L-section realization of simple voltage transfer ratios in w.

Network	Voltage transfer, $V_2/V_1(w)$
	$\frac{V_2}{V_1}(w) = \frac{R_o}{R}\left[\frac{1}{w+\alpha}\right]$ $\alpha = \frac{R_o}{R}$
	$\frac{R_2}{R_1+R_2}\left[\frac{w+\alpha}{w+\beta}\right]$ $\beta = \frac{R_o}{R_1+R_2} < \alpha = \frac{R_o}{R_2}$
	$\left[\frac{w+\alpha}{w+\beta}\right]$ $\alpha = \frac{R_2}{R_o} < \beta = \frac{R_1+R_2}{R_o}$
	$\left[\frac{\alpha^2+\beta^2}{(w+\alpha)^2+\beta^2}\right]$ $\alpha = \frac{R_{o2}}{2R}, \quad \alpha^2+\beta^2 = \frac{R_{o2}}{R_{o1}}$
	$\frac{R_1R_2}{R_{o1}(R_1+R_2)}\left[\frac{w+\gamma}{(w+\alpha)^2+\beta^2}\right]$ $\alpha = \frac{1}{2}\left(\frac{R_{o2}}{R_1+R_2}+\frac{R_1R_2}{R_{o1}(R_1+R_2)}\right)$ $\alpha^2+\beta^2 = \frac{R_{o2}R_2}{R_{o1}(R_1+R_2)}, \quad \gamma = \frac{R_{o2}}{R_1}$

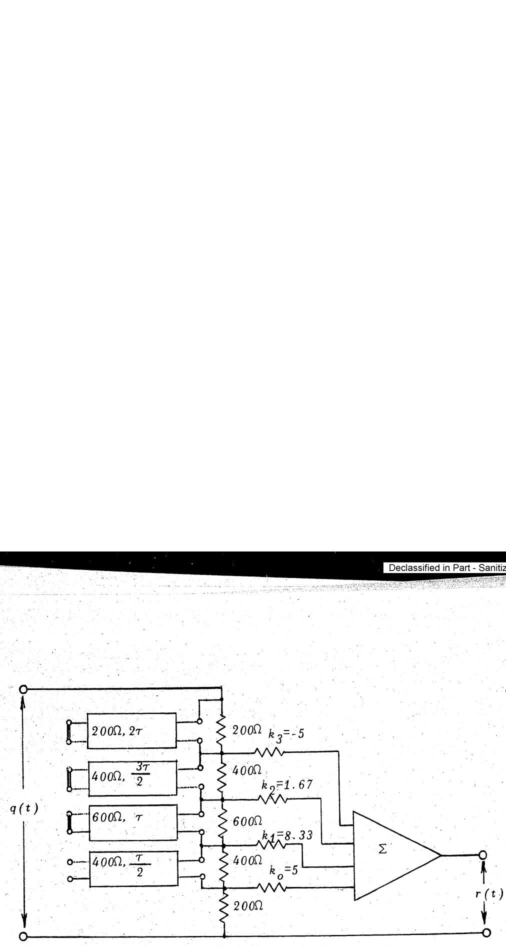


FIG. 5.20.--Network realization of time-domain equalizer.

The network of Fig. 5.20 is found directly from Eq. 5.53, which gives,

$$R_{on} = |2b_n| \quad , \qquad R = b_o - \sum_{n=1}^{4} |b_n|$$

The tap factors are found by Eq. 5.59.

$$a_3 = 1 = b_3 k_3 = -0.2k_3 \qquad k_3 = -5$$

$$a_2 = 1 = b_2(k_2 + k_3) \qquad k_2 = +1.67$$

$$a_1 = 1 = b_1(k_1 + k_2 + k_3) \qquad k_1 = +8.33$$

$$a_o = \left(k_o + \frac{a_1}{b_1}\right)\left(b_o - \sum_{n=1}^{4} |b_n|\right) + \sum_{n=1}^{4} \frac{a_n |b_n|}{b_n} \qquad k_o = 5$$

$$1 \equiv (k_o + 5)(0.2) + (-1)$$

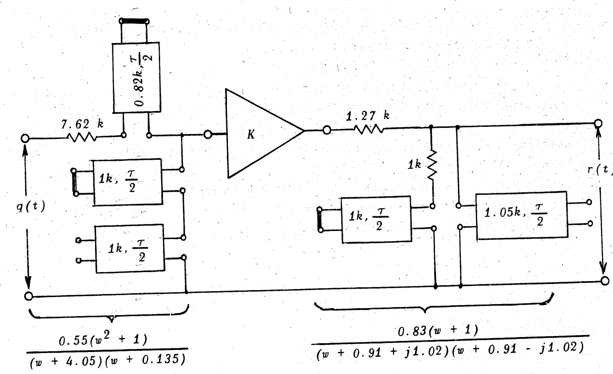


FIG. 5.21.--Network realization by w-plane method.

The w-plane method of synthesizing the time-domain equalizer of Fig. 5.12 proceeds by the substitution of $z = (1 - w)/(1 + w)$ into the transfer function $F(z)$ to form the transfer function $\mathcal{F}(w)$, rational in w.

For this example,

$$\mathcal{F}(w) = \frac{6.67(w + 1)(w^2 + 1)}{w^4 + 6w^3 + 10w^2 + 8.67w^1 + 1}$$

$$= \frac{6.67(w + 1)(w + j)(w - j)}{(w + 4.05)(w + 0.135)(w + 0.91 + j1.02)(w + 0.91 - j1.02)}$$

The network of Fig. 5.21 realizes this transfer function as a voltage transfer ratio by a cascade of simple L-section networks in a manner completely analogous to the realization of a four pole transfer function in s by means of lumped elements.

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E. FREQUENCY-DOMAIN SYNTHESIS

It was shown in Chapter IV that the frequency response of a network containing only delay lines and resistors must be a periodic function. This suggests that approximation to a prescribed response might be accomplished by a Fourier series. Fortunately, the individual terms in the Fourier series expansion have simple network realizations. For physical realizability, the real part of the frequency response must be even in ω and the imaginary part must be odd in ω. Accordingly, we would expect the result of the approximation problem to be in the series form of Eq. 5.63.

$$\mathcal{F}(\omega) = P(\omega) + jQ(\omega) = a_o + a_1 \cos \frac{2\pi\omega}{\omega_o} + a_2 \cos \frac{4\pi\omega}{\omega_o} + - - -$$

$$+ j \left[b_1 \sin \frac{2\pi\omega}{\omega_o} + b_2 \sin \frac{4\pi\omega}{\omega_o} + - \quad - \right] \qquad (5.63)$$

Where ω_o is the period of the frequency response.

The TDL filter is a very useful realization of Eq. 5.63. The transfer function for the TDL filter is a polynomial in z.

$$F(z) = f_o + f_1 z + f_2 z^2 + - - - f_n z^n + f_{n+1} z^{n+1} + - - - f_{2n} z^{2n} \qquad (5.64)$$

Let

$$z = e^{-j\omega\tau}$$

then

$$P(\omega) = f_o + f_1 \cos \omega\tau + f_2 \cos 2\omega\tau + - - - f_{2n} \cos 2n\omega\tau$$

$$\qquad (5.65)$$

$$Q(\omega) = -f_1 \sin \omega\tau - f_2 \sin 2\omega\tau - - \quad - - f_{2n} \sin 2n\omega\tau$$

Eq. 5.65 indicates that the real and imaginary parts in the $2n$-term expansion are not independant, hence an arbitrarily prescribed periodic frequency response could not be approximated. However, if a time delay of $n\tau$ can be tolerated at the output, the $2n$-tap TDL filter can yield an n-term expansion

for the real and imaginary parts independently. From Eq. 5.64.

$$F(z) = z^n (f_o z^{-n} + f_1 z^{-(n-1)} + f_2 z^{-(n-2)} + - - - f_n + - - - f_{2n} z^n) \quad (5.66)$$

Then

$$\mathcal{F}(\omega) = P(\omega) + jQ(\omega)$$

$$= e^{-j\omega n\tau} [(f_o + f_{2n}) \cos n\omega\tau + (f_1 + f_{2n-1}) \cos (n - 1) \omega\tau$$

$$+ (f_2 + f_{2n-2}) \cos (n - 2) \omega\tau + - - - (f_{n-1} + f_{n+1}) \cos \omega\tau + f_n]$$

$$+ je^{-j\omega n\tau} [(f_o - f_{2n}) \sin n\omega\tau + (f_1 - f_{2n-1}) \sin (n - 1) \omega\tau + - - -$$

$$- - - + (f_{n-1} - f_{n+1}) \sin \omega\tau] \qquad (5.67)$$

Comparing Eq. 5.67 with Eq. 5.63, we obtain

$$\omega_o = \frac{2\pi}{\tau}$$

$$\begin{aligned} a_o &= f_n & b_1 &= f_{n-1} - f_{n+1} \\ a_1 &= f_{n-1} + f_{n+1} & b_2 &= f_{n-2} - f_{n+2} \\ a_2 &= f_{n-2} + f_{n+2} & &\vdots \\ &\vdots & b_n &= f_o - f_{2n} \\ a_n &= f_o + f_{2n} & & \end{aligned} \qquad (5.68)$$

Thus by a suitable adjustment of the $2n + 1$ tap factors, f_k, the real and imaginary parts of an arbitrarily prescribed frequency response can be approximated by an n-term Fourier series, providing a time delay of $2\pi n/\omega_o$

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is allowed in the output. This implies that a linear phase component will be added to the phase of $\mathcal{F}(\omega)$ without the time delay.

$$\overline{\mathcal{F}(\omega)} = \tan^{-1} \frac{Q(\omega)}{P(\omega)} - \frac{2\pi n\omega}{\omega_o} \qquad (5.69)$$

The delay between taps on the TDL filter is $2\pi/\omega_o$.

The resulting frequency response, being periodic, will consist of an infinite number of equally separated pass bands. If only one or more of the pass bands is desired, the response at the remaining pass bands can be attenuated by cascading the network with a lumped element filter. If the lumped element filter is properly designed, the response in the desired pass bands will differ only slightly from $\mathcal{F}(\omega)$ whereas the response at the unwanted frequencies can be highly attenuated. Notice that this form of the combined transfer function, $H(s, z)$, is identical to the form found useful for the time-domain synthesis by the time-series method.

$$H(s, z) = G(s)\, F(z) \qquad (5.01)$$

In this case the part of the transfer function rational in s is used to select the desired pass bands; in the time-domain problem its purpose was to provide a suitable interpolation between sample values.

The TDL filter realization of an arbitrarily prescribed amplitude response with a linear phase response has been presented by Kallman[1] and by Corrington and Sonnenfeldt.[2] A slight modification of the TDL represents a saving of one-half the taps required for a given approximation.

Let

$$\mathcal{F}(\omega) = A(\omega)\, e^{-j(\omega/\omega_d)} \qquad (5.70)$$

We shall require only that $A(\omega)$ be real and as such it is not strictly an amplitude function, however, network analysis is greatly simplified by this alternate definition of amplitude and phase. In particular, this definition requires that the phase function be continuous in ω.

[1]H. E. Kallmann, "*Transversal Filters*," Proc. IRE, Vol. 28, July 1940, p. 302.

[2]M. S. Corrington and R. W. Sonnenfeldt, "*Synthesis of constant-time-delay networks*," RCA Rev., Vol. 15, June 1954, pp. 163-186.

Since $A(\omega)$ is periodic and even in ω, it can be approximated by a Fourier cosine series of period ω_o.

$$A(\omega) = a_o + a_1 \cos \frac{2\pi\omega}{\omega_o} + a_2 \cos \frac{4\pi\omega}{\omega_o} + - - - a_n \cos \frac{2\pi n\omega}{\omega_o} \qquad (5.71)$$

Comparing Eq. 5.71 with the transfer function of the TDL filter, we obtain

$$F(z) = z^n (f_o z^{-n} + f_1 z^{-(n-1)} + - - - f_n + - - - f_{2n} z^n) \qquad (5.66)$$

$$\mathcal{F}(\omega) = e^{-j\omega n\tau} [f_n + (f_{n-1} + f_{n+1}) \cos \omega\tau + (f_{n-2} + f_{n+2}) \cos 2\omega\tau$$

$$+ - - - + (f_o + f_{2n}) \cos n\omega\tau] \qquad (5.67)$$

if

$$f_{n-j} = f_{n+j} \qquad (5.72)$$

So that

$$a_o = f_n$$

$$a_1 = f_{n-1} + f_{n+1} \qquad \omega_o = \frac{2\pi}{\tau}$$

$$\vdots \qquad\qquad (5.73)$$

$$\omega_d = \frac{n}{\tau}$$

$$a_n = f_o + f_{2n}$$

The condition of Eq. 5.72 can be met with an $(n + 1)$-tap TDL filter with the nth delay section terminated in an open-circuit and with a non-reflecting termination on the input end, as shown in Fig. 5.22. As an illustration of the possibilities of this type of frequency-domain synthesis, consider the prescribed amplitude response to be the rectangular response of an ideal low pass filter with an associated linear phase.

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a) Fourier approximation to frequency response of an ideal low-pass filter.

b) TDL realization of frequency response of (a).

FIG. 5.22.--TDL filter approximation to frequency response of an ideal low-pass filter.

The periodic extention of this prescribed response can be considered to be a square wave in ω. The tap factors are then just the Fourier coefficients for the expansion of a square wave. As the number of terms in the expansion is increased, the transition in the cutoff region is made sharper but the delay of the filter is increased correspondingly. A lumped-element filter attenuates the response in the higher frequency pass bands.

Frequency-domain synthesis with networks containing delay lines offers several advantages over synthesis by lumped-element networks. The example of Fig. 5.22 shows that a very sharp cutoff can be obtained simultaneously with linear phase through the cutoff region. This is extremely difficult to accomplish with lumped-element networks. Another advantage is in the alignability of the TDL filter realization; the tap factors individually control the coefficients of the series expansion of the frequency response. Also, the correlation between frequency response and the time response is very direct since $F(z)$ gives a time series representation for the impulse response.

Another approach to the synthesis for a prescribed periodic frequency response with networks containing only delay lines and resistors is to transform the prescribed response data in the interval

$$-\frac{\omega_o}{2} \leq \omega \leq \frac{\omega_o}{2}$$

to the complete imaginary axis in the w-plane. Now this transformed prescribed data can be approximated by a function rational in w satisfying certain physical realizability conditions. The realization then follows the methods indicated in the previous section similar to the realization procedures for lumped element networks.

VI. CONCLUSION

A. SUMMARY

There is no doubt that the use of delay-line elements greatly extends the class of response functions realizable by linear networks. For this reason, the delay line should always be included among the available elements for network synthesis, especially in those cases where the prescribed impulse response contains discontinuities or sharp corners and where the fine structure of a filter spectrum must be carefully controlled.

The nature of the transfer functions of line-lumped networks makes feasible the design of linear ''pulse corrector'' or ''time-domain equalizer'' networks for the purpose of eliminating undesirable overshoots or otherwise reshaping time functions to some prescribed form. Using time-series methods the time-domain synthesis is greatly simplified, especially in cases where the designer must work from empirical data. The z-transform is a particularly useful form of time-series representation; first, because the transfer functions for delay-line and resistor networks are rational in z, and second, because z-transform theory has already been well developed for use in the analysis of sampled-data systems.

Special emphasis has been placed on synthesis of impulse responses having limited time duration and hence avoiding the objectionable ''tails'' invariably associated with the response of lumped-element networks. This property is probably one of the most outstanding examples of the practical application of line-lumped networks.

Some of the network realizations of Chapter V have the advantage of a high degree of alignability. For instance, the TDL filter has an impulse response for which each response parameter (sample value) is independently controlled by a single network parameter (tap factor). An excellent example of the utility of the TDL filter is presented in a report by D. W. Lytle.[1] In this case, it was required to design a filter whose impulse response is a very complex time function matched to a particular noise-like input signal; namely, a pseudo-random binary sequence of pulses. This type of response would be very difficult to approximate with lumped-element networks.

The fact that good-quality delay-line elements are readily available to the network designer in a wide range of characteristic impedances and phase velocities is more than ample justification for undertaking a study of this nature. It is hoped that the ideas presented in the preceding chapters will stimulate an interest toward further investigation of the problem.

[1] D. W. Lytle, ''*On the properties of matched filters*,'' TR No. 17, Stanford Electronics Laboratory, Stanford, California, June 1957.

B. SOME SUGGESTIONS FOR FURTHER STUDY

An interesting topic in frequency-domain synthesis is the general theory of approximating a prescribed frequency response by ''all-zero'' transfer functions having pulse-function impulse response. Preliminary investigations indicate that this new approach might yield some useful results. For instance, a sampled-data procedure analogous to that used in the time domain might be used for frequency-domain synthesis. The method would involve approximating the prescribed frequency response by functions passing through the prescribed sample values at a discrete set of frequencies. The ''all-zero'' transfer function is a logical choice for an interpolating function to give the proper behavior in the intersample region. A technique of this sort would be especially valuable when the prescribed response is given experimentally in terms of measurements at discrete frequencies. Another point to consider is that there may exist possibilities for simultaneous approximation in the time domain and the frequency domain.

A vast new set of possibilities for network synthesis becomes apparent when distributed coupling between the delay-line elements is considered. A paper by B. M. Oliver[1] indicates some of the transient response properties of coupled lines when the degree of coupling is a function of distance. Even artificial lines with discrete coupling could be very useful elements for low-frequency networks and could be represented by ideal delay lines with a prescribed distributed coupling.

The synthesis methods of Chapter V consider a rather specialized form of the transfer functions of line-lumped networks. The development of a more general procedure may reveal some important results.

ACKNOWLEDGMENT

The author would like to express his appreciation for the encouragement and advice given by Dr. W. W. Harman under whose supervision this study was undertaken.

[1] B. M. Oliver, ''*Directional electromagnetic couplers*,'' Proc. IRE, vol. 42, November 1954, pp. 1686-1692.

APPENDIX A: REDUCTION OF THE RANK OF A SCATTERING MATRIX

Suppose an n-terminal-pair network has a specific connection of elements at j of the pairs. The scattering matrix of rank n for the network can be reduced to a matrix of rank $n - j$, corresponding to the remaining unspecified or ''accessible'' pairs. This results from the fact that j constraints have been placed on the relations between incident and reflected waves at the j pairs. Consider, for example, the network of Fig. A-1, where the jth terminal pair is connected to a terminated delay line.[1] The constraint imposed at the jth pair is that

$$A_j = \gamma_j B_j$$

where

$$\gamma_j = \rho_j e^{-2sT_j} \qquad (A\text{-}1)$$

$$B_k = \sum_{i=1}^{n} s_{ki} A_i = \sum_{\substack{i=1 \\ i \neq j}}^{n} s_{ki} A_i + s_{kj} \gamma_j B_j \qquad (A\text{-}2)$$

Solving for A_j,

$$A_j = \frac{\gamma_j}{1 - s_{jj}\gamma_j} \sum_{\substack{i=1 \\ i \neq j}}^{n} s_{ji} A_i$$

Then

$$B_k = \sum_{\substack{i=1 \\ i \neq j}}^{n} s_{ki} A_i + \frac{\gamma_j s_{kj}}{1 - s_{jj}\gamma_j} \sum_{\substack{i=1 \\ i \neq j}}^{n} s_{ji} A_i \qquad (A\text{-}3)$$

Hence the elements, s'_{ki}, of the reduced scattering matrix, S', are given by:

$$s'_{ki} = s_{ki} + \frac{\gamma_j}{1 - s_{jj}\gamma_j} s_{kj} s_{ji} \qquad (A\text{-}4)$$
$$k, i \neq j$$

The jth pair is completely eliminated from the matrix.

[1] For simplicity, delay elements will be represented symbolically by single lines in this appendix.

This method is useful for reduction of the rank of the scattering matrix for simple networks, but the expressions become very cumbersome for more complicated networks. An interesting matrix procedure for reduction of the rank of a scattering matrix is developed in a paper by R. H. Dicke.[1] An outline of the procedure is presented here.

The problem will be stated as follows: Given the scattering matrices S_p and S_q of p-pair and q-pair networks respectively, when r of the pairs on each network are interconnected through delay lines, what is the scattering matrix of the combined network in terms of the $p + q - 2r$ remaining pairs? The matrices, S_1 and S_2, of rank $p + q - r$ are the scattering matrices of the networks with the arbitrarily placed reference plane of Fig. A-2. S_1 and S_2 are easily derived from S_p and S_q with the aid of Eq. 2.16.

$$S_1 = \left(\begin{array}{c:c:c} & & 0 \\ \hdashline & & 0 \\ \hdashline 0 & 0 & 0 \end{array}\right) \begin{array}{l} \}\, p-r \\ \}\, r \\ \}\, q-r \end{array}$$
$$\qquad \underbrace{\ \ }_{p-r}\ \underbrace{\ \ }_{r}\ \underbrace{\ \ }_{q-r}$$

$$(A\text{-}5)$$

$$S_2 = \left(\begin{array}{c:c:c} 0 & 0 & 0 \\ \hdashline 0 & & \\ \hdashline 0 & & \end{array}\right) \begin{array}{l} \}\, p-r \\ \}\, r \\ \}\, q-r \end{array}$$
$$\qquad \underbrace{\ \ }_{p-r}\ \underbrace{\ \ }_{r}\ \underbrace{\ \ }_{q-r}$$

So that

$$B_1 = S_1 A_1$$

$$B_2 = S_2 A_2$$

[1] R. H. Dicke, ''A computational method applicable to microwave networks,'' J. Appl. Phys., Vol. 18, October 1947, pp. 873-878.

FIG. A-1.--Simple termination on jth pair.

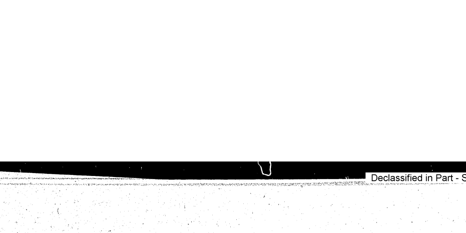

FIG. A-2.--Interconnection of two networks with delay lines.

Two auxiliary matrices are introduced to facilitate the solution

$$\left.\begin{aligned} G &\triangleq \begin{array}{c} \left(\begin{array}{c|c|c} 0 & 0 & 0 \\ \hline 0 & \mathsf{I} & 0 \\ \hline 0 & 0 & 0 \end{array}\right) \begin{array}{l} \}\, p-r \\ \}\, r \\ \}\, q-r \end{array} \\ \underbrace{\quad}_{p-r}\ \underbrace{\quad}_{r}\ \underbrace{\quad}_{q-r} \end{array} \\ H &\triangleq \mathsf{I} - G \end{aligned}\right\} \qquad (A\text{-}6)$$

Note that the central sub-matrix of H is a null matrix. We want to express the reduced scattering matrix, S, in terms of H such that the elements of the r central rows and columns of S are all zero. Then the rank of S will be $p + q - 2r$

The constraints at the reference plane are expressed by Eq. A-7.

$$\left.\begin{aligned} GA_1 &= GB_2 \\ GB_1 &= GA_2 \end{aligned}\right\} \qquad (A\text{-}7)$$

Combining these equations,

$$\left.\begin{aligned} B_1 &= S_1A_1 = S_1GA_1 + S_1HA_1 \\ &= S_1GB_2 + S_1HA_1 = S_1GS_2A_2 + S_1HA_1 \\ &= S_1GS_2GA_2 + S_1GS_2HA_2 + S_1HA_1 \end{aligned}\right\} \qquad (A\text{-}8)$$

Let

$$M = S_1GS_2G\,, \qquad N = S_1GS_2 \qquad (A\text{-}9)$$

Then

$$B_1 = MA_2 + NHA_2 + S_1HA_1 \qquad (A\text{-}10)$$

Multiplying Eq. A-10 by M,

$$MB_1 = M^2A_2 + MNHA_2 + MS_1HA_1$$

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but

$$MB_1 = MA_2$$

so

$$B_1 = M^2A_2 + MNHA_2 + MS_1HA_1 + NHA_2 + S_1HA_1$$

Continuing the process of multiplying by M, we obtain the following sequence of equations.

$$\begin{aligned} B_1 &= MA_2 + NHA_2 + S_1HA_1 \\ &= M^2A_2 + (M + I)[NHA_2 + S_1HA_1] \\ &= M^3A_2 + (M^2 + M + I)[NHA_2 + S_1HA_1] \qquad (A\text{-}11) \\ &\quad \vdots \\ &= M^nA_2 + (M^{n-1} + \cdots + I)[NHA_2 + S_1HA_1] \end{aligned}$$

From the Hamilton-Cayley theorem M is a solution of the characteristic equation of the matrix as shown in Eq. A-12.

$$det\ (M - \lambda I) = \sum_{n=1}^{r+1} C_n\lambda^n = 0 \qquad (A\text{-}12)$$

Therefore[1]

$$\sum_{n=1}^{r+1} C_nM^n = 0 \qquad (A\text{-}13)$$

The sum of the coefficients can be normalized such that

$$\sum_{n=1}^{r+1} C_n = 1 \qquad (A\text{-}14)$$

[1]It can be shown that $C_o = 0$.

If Eqs. A-11 are multiplied by C_1, C_2, C_3 - - - C_{r+1} and added, we obtain

$$\sum_{n=1}^{r+1} C_nB_1 = \left[\sum_{n=1}^{r+1} C_nM^n\right] A_2 + \sum_{n=1}^{r+1} C_n[NHA_2 + S_1HA_1]$$

$$+ \sum_{n=2}^{r+1} C_nM[NHA_2 + S_1HA_1] + \sum_{n=3}^{r+1} C_nM^2[NHA_2 + S_1HA_1]$$

$$+ \cdots \qquad (A\text{-}15)$$

Substituting Eqs. A-13 and A-14 into Eq. A-15

$$B_1 = [I + (1 - C_1)M + (1 - C_1 - C_2)M^2 + \cdots][NHA_2 + S_1HA_1] \qquad (A\text{-}16)$$

Since

$$S_1HA_2 = NHA_1 = 0$$

$$[NHA_2 + S_1HA_1] = (N + S_1)\ H\ (A_1 + A_2) \qquad (A\text{-}17)$$

$$B_2 = S_2A_2 = S_2GB_1 + S_2HA_2 \qquad (A\text{-}18)$$

For the combined network,

$$(B_1 + B_2) = S(A_1 + A_2) \qquad (A\text{-}19)$$

Solving for S from Eqs. A-16, 17, 18, and 19

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$$S = H\{S_2 + (I + S_2G)[I + (1 - C_1)M + (1 - C_1 - C_2)M$$

$$+ - - -](N + S_1)\}H$$

$$S = \begin{array}{cl} \left(\begin{array}{c:c:c} & 0 & \\ \hdashline 0 & 0 & 0 \\ \hdashline & 0 & \end{array}\right) & \begin{array}{l} \}\, p-r \\ \}\, r \\ \}\, q-r \end{array} \\ \begin{array}{ccc} \underbrace{\quad}_{p-r} & \underbrace{\quad}_{r} & \underbrace{\quad}_{q-r} \end{array} & \end{array} \qquad (A\text{-}20)$$

Thus the scattering matrix for the combined network can be collapsed into a matrix containing $p + q - 2r$ rows and columns.

APPENDIX B: RELATION BETWEEN LAPLACE TRANSFORMS AND z-TRANSFORMS FOR MULTIPLE ORDER POLES

To find the z-transform correspondence to higher order terms of the partial fraction expansion of the Laplace transform, we use the correspondence,

$$\frac{\partial^n}{\partial s^n} F(s) \rightarrow \frac{\partial^n}{\partial s^n} F^*(e^{-s\tau}) \qquad (B\text{-}1)$$

In particular,

$$\frac{\partial}{\partial s}\left(\frac{1}{s}\right) = -\frac{1}{s^2} \rightarrow \frac{\partial}{\partial s}\left(\frac{1}{1 - e^{-s\tau}}\right) = \frac{-\tau e^{-s\tau}}{(1 - e^{-s\tau})^2}$$

Making the substitution, $z = e^{-s\tau}$, we have

$$\frac{1}{s^2} \rightarrow \frac{\tau z}{(z - 1)^2} \qquad (B\text{-}2)$$

Similarly,

$$\frac{\partial^2}{\partial s^2}\left(\frac{1}{s}\right) = \frac{2}{s^3} \rightarrow \frac{\partial^2}{\partial s^2}\left(\frac{1}{1 - e^{-s\tau}}\right) = \frac{\tau^2 e^{-s\tau}(1 + e^{-s\tau})}{(1 - e^{-s\tau})^3}$$

$$\frac{1}{s^3} \rightarrow -\frac{\tau^2}{2}\frac{z(z + 1)}{(z - 1)^3} \qquad (B\text{-}3)$$

and,

$$\frac{\partial^3}{\partial s^3}\left(\frac{1}{s}\right) = -\frac{6}{s^4} \rightarrow \frac{\partial^3}{\partial s^3}\left(\frac{1}{1 - e^{-s\tau}}\right) = -\frac{\tau^3 e^{-s\tau}[1 + 4e^{-s\tau} + e^{-2s\tau}]}{(1 - e^{-s\tau})^4}$$

$$\frac{1}{s^4} \rightarrow \frac{\tau^3}{6}\frac{z(z^2 + 4z + 1)}{(z - 1)^4} \qquad (B\text{-}4)$$

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For multiple order poles removed from the origin in s, the relation of row 24 Table I may be applied.

$$F(s + \alpha) \rightarrow F^*(e^{-\alpha\tau}z) \tag{B-5}$$

For instance, combining Eqs. B-3 and B-5,

$$\frac{1}{(s+\alpha)^3} \rightarrow -\frac{\tau^2 e^{\alpha\tau} z(z + e^{\alpha\tau})}{2\,(z - e^{\alpha\tau})^3} \tag{B-6}$$

To identify the Laplace transform of the continuous time function from the higher order terms in the partial fraction expansion of the z-transform, an iterative procedure is used.

Since

$$\frac{1}{(s+\alpha)^2} \rightarrow \frac{\tau e^{\alpha\tau} z}{(z - e^{\alpha\tau})^2}$$

$$\frac{1}{(s+\alpha)^2} \rightarrow \frac{\tau e^{2\alpha\tau}}{(z - e^{\alpha\tau})^2} + \frac{\tau e^{\alpha\tau}}{(z - e^{\alpha\tau})}$$

$$\frac{1}{(s+\alpha)^2} + \frac{\tau}{(s \mp \alpha)} \rightarrow \frac{\tau e^{2\alpha\tau}}{(z - e^{\alpha\tau})^2}$$

or:

$$\frac{1}{(z-a)^2} \leftarrow \frac{\frac{1}{\tau a^2}}{\left(s + \frac{1}{\tau}\log a\right)^2} + \frac{\frac{1}{a^2}}{\left(s + \frac{1}{\tau}\log a\right)} \tag{B-7}$$

$$f(t) = \frac{t}{\tau a^2}\, a^{-t/\tau} + \frac{1}{a^2}\, a^{-t/\tau}$$

Similarly;

$$\frac{1}{(s+\alpha)^3} \rightarrow -\frac{\tau^2}{2}\,\frac{e^{\alpha\tau} z(z + e^{\alpha\tau})}{(z - e^{\alpha\tau})^3}$$

$$\rightarrow -\frac{\tau^2}{2}\, e^{\alpha\tau}\left[\frac{2e^{2\alpha\tau}}{(z - e^{\alpha\tau})^3} + \frac{3e^{\alpha\tau}}{(z - e^{\alpha\tau})^2} + \frac{1}{z - e^{\alpha\tau}}\right]$$

$$\frac{1}{(s+\alpha)^3} + \frac{3\tau}{2}\left[\frac{1}{(s+\alpha)^2} + \frac{\tau}{s+\alpha}\right] - \frac{\frac{\tau^2}{2}}{s+\alpha} \rightarrow -\frac{\tau^2 e^{3\alpha\tau}}{(z - e^{\alpha\tau})^3}$$

or;

$$\frac{1}{(z-a)^3} \leftarrow -\frac{1}{\tau^2 a^3}\left[\frac{1}{\left(s + \frac{1}{\tau}\log a\right)^3} + \frac{\frac{3\tau}{2}}{\left(s + \frac{1}{\tau}\log a\right)^2} + \frac{\tau^2}{\left(s + \frac{1}{\tau}\log a\right)}\right] \tag{B-8}$$

APPENDIX C: CASCADE REALIZATION OF A PERIODIC REACTANCE FUNCTION

Any reactance function rational in w (or z) and hence periodic in ω with period, $2\pi/\tau$, can be realized as a cascade of delay lines of length, $\tau/2$, by a method suggested by Richards.[1] The driving-point impedance Z in Fig. C-1 is given by Eq. C-2 and is a reactance function if the termination Z' is a reactance function.

$$Z = R_o \left[\frac{1 + \left(\frac{Z' - R_o}{Z' + R_o} \right) z}{1 - \left(\frac{Z' - R_o}{Z' + R_o} \right) z} \right] \qquad (C\text{-}1)$$

Substituting $z = (1 - w)/(1 + w)$;

$$Z(w) = R_o \left[\frac{Z' + R_o w}{R_o + Z' w} \right] \qquad (C\text{-}2)$$

then,

$$Z'(w) = \frac{Z(w) - R_o w}{1 - \frac{Z(w)}{R_o} w} = \frac{A(w)}{B(w)} \qquad (C\text{-}3)$$

If $R_o = Z(1)$ then $Z'(w)$ is of lower degree than $Z(w)$. In fact, the numerator and denominator of Eq. C-3 will both contain a factor, $(w^2 - 1)$.

$$\begin{aligned} A(1) &= Z(1) - R_o = 0 \\ B(1) &= 1 - \frac{Z(1)}{R_o} = 0 \end{aligned} \qquad (C\text{-}4)$$

hence $(w - 1)$ is a common factor of A and B.

From Eq. C-2,

$$Z(-1) = -Z(1) \qquad (C\text{-}5)$$

[1] P. I. Richards, ''*Resistor-transmission-line circuits,*'' Proc. IRE, Vol. 36, February 1948, pp. 217-220.

$$\begin{aligned} A(-1) &= -Z(1) + R_o = 0 \\ B(-1) &= 1 - \frac{Z(1)}{R_o} = 0 \end{aligned} \qquad (C\text{-}6)$$

so that $(w + 1)$ is also a common factor of A and B, and by dividing A and B by $(w^2 - 1)$ the resulting Z' is of lower degree than Z. The same process is applied to Z' yielding a new termination Z'' of still lower degree. Eventually the process leads to an impedance $R_{on} w$ or R_{on}/w which can be realized by a short-circuit or open-circuit terminated delay line as in Fig. C-2.

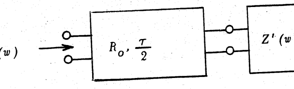
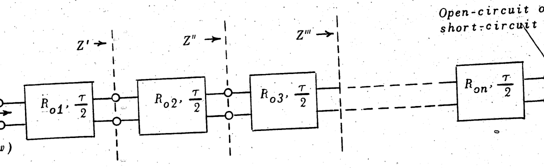


FIG. C-1.--Driving-point impedance of delay line with reactance termination.



$R_{o1} = Z(1) \qquad R_{o2} = Z'(1) \qquad R_{o3} = Z''(1)$ - - -

FIG. C-2.--Realization of reactance function rational in w.

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